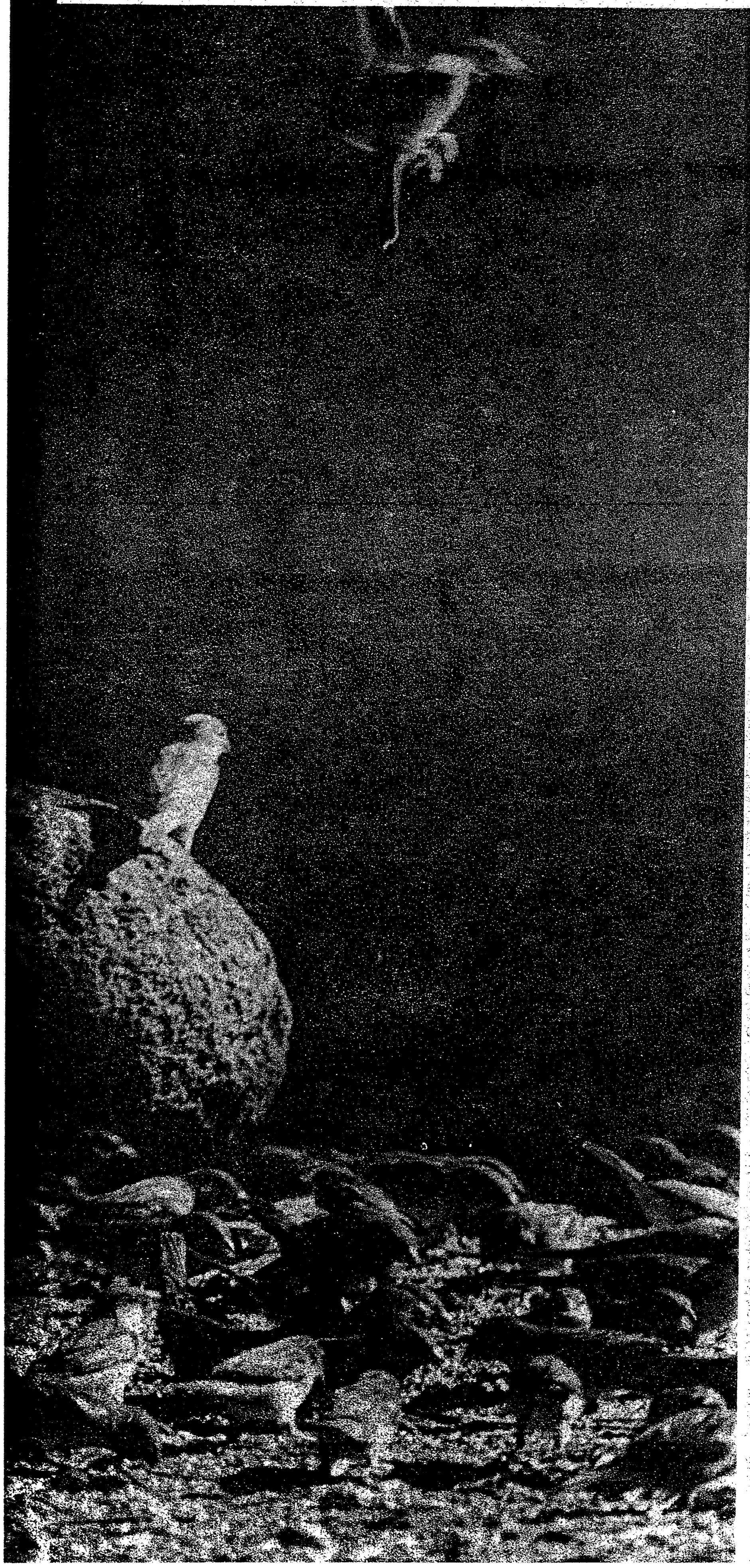
ARIZONA GAME AND FISH DEPARTMENT



RESEARCH BRANCH
TECHNICAL REPORT #20

RELATIONSHIPS OF BIRDS, LIZARDS, AND NOCTURNAL RODENTS TO THEIR HABITAT IN THE GREATER TUCSON AREA, ARIZONA

A Final Report

STEPHEN S. GERMAINE

October 1995

ARIZONA GAME AND FISH
DEPARTMENT HERITAGE FUND

Arizona Game and Fish Department Mission

To conserve, enhance, and restore Arizona's diverse wildlife resources and habitats through aggressive protection and management programs, and to provide wildlife resources and safe watercraft and off-highway vehicle recreation for the enjoyment, appreciation, and use by present and future generations.

Arizona Game and Fish Department
Research Branch

Technical Report Number 20

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Suggested Citation:
Germaine, S. S. 1995. Relationships of birds, lizards, and nocturnal rodents to their habitat in the greater Tucson area, Arizona. Ariz. Game and Fish Dep. Tech. Rep. 20, Phoenix. 47pp.

ISSN 1052-7621
ISBN 0-917-563-27-1

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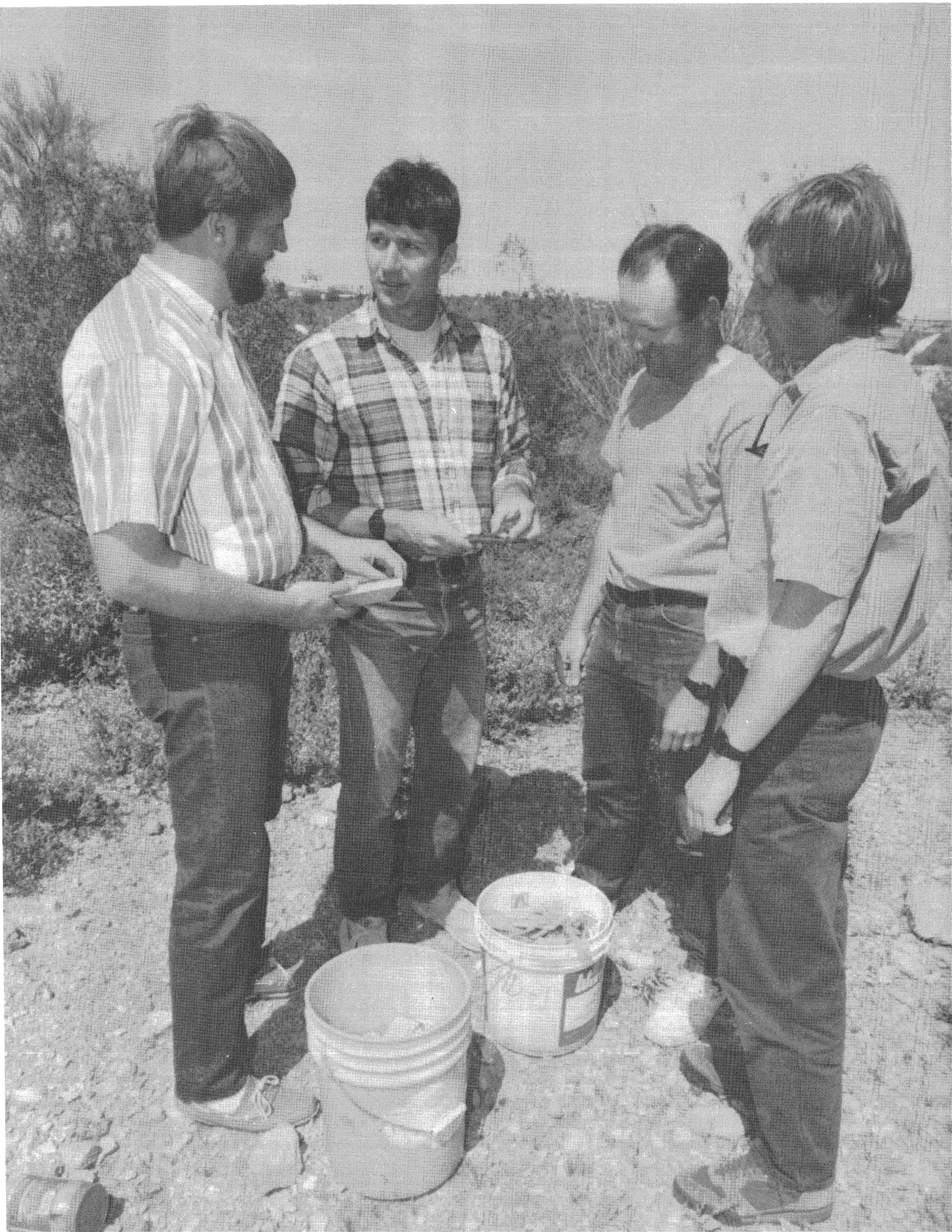


ACKNOWLEDGEMENTS

This project benefitted from the assistance of many people, all of whom deserve credit for its successful completion. Dave Belitsky, Glenn Frederick, Carl Gustavson, Jeff Howland, Ron Olding, Ray Schweinsburg, Bill Shaw, Steve Rosenstock, and Bill Van Pelt all provided thoughtful input into various segments of the research design. Volunteers Dale Bode, Jim Cummings, Ashley Dickson, Jr., Muriel Deroek, Heather Eggleston, Pat Frawley, Colby Henley, Joe Hoscheidt, Dorothy Tinkler, and John Simms were vital to the success of the nocturnal rodent study. Glenn Frederick, John McGehee, Dave Neill, Ron Olding, Scott Richardson, Ray Schweinsburg, and Dan Smith also contributed their time to the benefit of the rodent study. Yar Petryszyn generously aided in the identification of all rodent species captured. Terry Frederick and Jeff Howland offered advice on lizard survey techniques in urban environments, and Terry also trained me on lizard survey procedures. John Kolozar is responsible for the success of the habitat quantification and land cover classifications. Thank you John. Jenny Wennerlund and Scott Woods prepared detailed Geographic Information System plots of greater Tucson and the study areas. Critical reviews of drafts of the report were provided by Lowell Adams, Vanessa Dickenson, Lisa Harris, Richard Ockenfels, Scott Richardson, Steve Rosenstock, Ray Schweinsburg, Bill Shaw, Brian Wakeling, Jody Walters, and Joe Yarchin. Finally, thanks to Gerry Perry and the Region 5 office staff for their support of this project. Thanks to Vicki Webb for contributing her expertise during typsetting and layout.

This project was financially supported by a grant from the Arizona Game and Fish Department Heritage Fund, awarded to Glenn P. Frederick. The Arizona Game and Fish Department Heritage Fund was designed to conserve, enhance, and establish wildlife habitats and populations in urban environments, and to increase public awareness of urban wildlife resources.

Relationships of Birds, Lizards, and Nocturnal Rodents to Their Habitat in the Greater Tucson Area, Arizona

Stephen S. Germaine

Abstract: I examined population and community descriptors of 3 wildlife assemblages across the residential gradient from undisturbed-natural to highly developed land in Tucson, Arizona, from March 1994 through February 1995. Breeding birds were sampled in 334 random plots, and wintering birds and lizards were sampled in subsets of 305 and 130 plots, respectively. In addition, I sampled nocturnal rodents at 8 sites representing 3 housing densities. Land cover type, habitat structure, plant species composition, and distances from population refugia were measured in all plots. I identified habitat associations for breeding bird, wintering bird, and lizard species. Housing density best explained the variation in species richness for non-native, native, and an indicator guild of breeding birds, and for lizards. The percent of paved areas, exotic, upper Sonoran, and undisturbed riparian vegetation in plots, and distance from undisturbed washes also predicted bird and lizard species richness. Lizard abundance was best explained by the amount of lower Sonoran vegetation and undisturbed riparian vegetation within plots. House mice (*Mus musculus*) were the only nocturnal rodents encountered in high density (7.5 houses/ha) housing areas. Two of the native rodent species were less abundant in the high density control than in low density (0.5 houses/ha) areas. While rodent species richness did not differ significantly among levels of housing density, total abundance was lower in the high density housing and control. Development strategies for optimizing urban wildlife habitat in Tucson in the future are discussed.

INTRODUCTION

Development of rural lands surrounding metropolitan areas has become a major factor contributing to the destruction of natural habitats. Residential and commercial development of rural areas is occurring in most states, and is expected to continue for several decades. For example, over 80% of the human population in Arizona lives in metropolitan areas; these areas are rapidly expanding and fragmenting native habitat. Arizona is currently the 5th fastest growing state in the United States (O'Leary Morgan et al. 1991), and Tucson is the 3rd fastest growing city in Arizona (Hazard and Burchell 1991).

As urban development progresses outward, native habitats become incorporated into the suburban matrix, and many suburban areas become increasingly isolated from contiguous blocks of native habitat. In these developing areas, blocks of native vegetation become fragmented and insularized, creating a patchwork matrix of native habitat islands that have been altered by varying degrees from their natural state. As urban development continues, distances between these islands and the edge of the undeveloped areas "mainland" (MacArthur and Wilson 1967) increase. Mainland is here defined as the undeveloped desert surrounding Tucson which serves as a population source for the native species. Small isolated blocks of natural habitat are of questionable value to native wildlife (Wilcove 1985, Soule et al. 1988, Bolger et al. 1991).

As island to mainland distance increases, immigration from source populations generally decreases, and only those species with high dispersal capabilities may reach the more isolated islands. Also, as island size decreases extinction rates increase, due to the island's diminished ability to support as many individuals per species (MacArthur and Wilson 1963, Lynch and Whigham 1984). Isolated blocks (islands) are often structurally and floristically altered by human and vehicular traffic, trash dumping, competition from introduced plants, modified precipitation runoff patterns, and otherwise altered by the presence of feral predators (Whitcomb 1977, Adams 1994).

Natural habitat corridors in developed areas are usually confined to riparian zones or powerline rights-of-way where the vegetation is often degraded (modified from natural conditions) and frequently fragmented by roads or other human-made obstacles. While probably not limiting bird dispersal, roads can have major detrimental effects on the dispersal of herpetofauna (Minton 1968, Gibbs et al. 1971) and small mammals (Oxley et al. 1974). Furthermore, the utility of corridors as important wildlife dispersal routes has been seriously questioned (Simberloff et al. 1992).

Developed land parcels become less similar to native habitat, due to the increasing presence of structures (e.g., houses, outbuildings, apartment complexes), paved areas, altered vegetation, and direct human and pet-related disturbances to native wildlife. As a result, developed areas become less able to support populations of many native wildlife species (Gavareski 1976, Green 1984, Sears and Anderson 1991).

In this study, I examined the relationship between wildlife and factors describing residential urbanization in Tucson, Arizona. I included 3 groups of animals in this study: birds, lizards, and nocturnal rodents. Other researchers have identified factors which influence the distributions of each of these groups across urban gradients.

Birds. In Tucson, descriptive comparisons have been made for birds between undeveloped and developed land parcels which were otherwise similar. Emlen (1974) compared community composition between a residential area and an undeveloped desert area and emphasized the avian resources present at each site. Tweit and Tweit (1986) used data from existing Tucson area studies to summarize avian community composition in various habitat types. They also summarized important habitat types for individual birds. Mills et al. (1989) documented relationships between the volume of native and exotic vegetation and breeding bird abundance, density, and diversity. Stenberg (1988) compared land cover composition to the number of species present and identified elements of the metropolitan environment that were important in predicting bird species richness.

Research needed to be conducted in Tucson that identified ecologically important habitat factors throughout the urban residential spectrum. In addition, predictive models that incorporated habitat variables and objective community response variables needed to be generated. The relationship among community parameters such as abundance, richness, and evenness had to be identified to determine how wildlife community regulatory mechanisms are affected by residential factors. Further, while habitat associations have been reported for many bird species, no effort had been made to identify thresholds beyond which individual species declined.

Lizards. Little information exists on the distributions of lizards in urban areas in the Southwest. Morrison et al. (1994) documented the loss of 3 lizard and 11 snake species from an urban park in San Diego, CA. They implicated physiognomic and floristic changes in the habitat, high levels of human disturbance, and the presence of feral predators. Additionally, herpetofauna populations have been impacted by factors such as destruction of protective ground cover (Minton 1968, Orser and Shure 1972), the presence of roads (Gibbs et al. 1971) and window wells (Heck 1971), increased predation rates (Schaaf and Garton 1970), collecting (Beebe 1973), and pollution and pesticides (Anderson 1965, Scott 1973). To date, no study in the Southwest has quantified factors associating residential urbanization with lizard assemblages and populations.

Nocturnal Rodents. Comparing an urban park and an undisturbed control, Morrison et al. (1994) determined that the small mammal assemblage in the park was impoverished and dominated by the exotic house mouse. They reported the disappearance of 9 insectivore and rodent species from the park area, and cited competition from house mice (*Mus musculus*) and habitat degradation as potential causal factors. Stenberg (1988) surveyed sign (scat, tracks, den holes) in Tucson, and reported that small mammals seemed to follow a concentric pattern of distribution around the metropolitan center, with overall diversity declining as urbanization increased. Duncan (1990) conducted a preliminary study on the effects of visitor use on vegetation and nocturnal rodent populations in Saguaro National Park, Tucson. Although he found vegetative differences between experimental and control sites, he could not attribute them to human use, and he found few differences in rodent densities.

Other factors found to affect rodent distributions in urban areas include habitat patch isolation (Goszczynski 1979a), dogs and cats (Goszczynski 1979b), vegetation alterations (Dickman and Doncaster 1987, 1989), and roads (Oxley et al. 1974). No information exists in the Southwest on the effects of quantifiable factors associated with residential urbanization on nocturnal rodent assemblages and populations.

Study Objectives

My primary goal was to develop habitat models which would accurately predict the distribution of birds and lizards throughout the urban residential gradient in Tucson, Arizona. Because land use planners and developers affect habitat changes in the form of large scale ground cover changes, I tested hypotheses concerning cover type use by birds, lizards, and nocturnal rodents throughout the urban residential landscape. My specific objectives were to:

- Describe the distributions and associations of existing land cover types currently present in the greater Tucson area;

- Associate breeding and wintering bird species abundances with habitat variables that describe structure (physiognomy), vegetation (floristics), and distances from potential wildlife population sources and dispersal routes;

- Develop models to predict breeding bird species richness (number of species) across the residential gradient;

- Associate lizard species abundances with habitat variables that describe physiognomy, floristics, and distances from potential wildlife population sources and dispersal routes;

- Develop models to predict lizard species richness and total abundance across the residential gradient;

- Identify the regulatory mechanisms of bird and lizard communities by examining the correlation structure among species richness, abundance, evenness (measure of equality of abundances among species), and habitat variables; and

- Compare distributions of nocturnal rodent species between residential areas differing in housing density (as similar as possible in all other regards).

STUDY AREA

This study was conducted in the greater Tucson metropolitan area, in southeastern Arizona (Fig. 1). Tucson lies within the Sonoran Desert, and contains both lower and upper Sonoran vegetative types, as well as vegetation types associated with riparian corridors (mixed riparian desert scrub series; Brown et al. 1979). While relicts of these communities can be found, much of the urban landscape has been disturbed, landscaped with exotics, or otherwise modified (W. Shaw. Univ. of Ariz., pers. commun.).

The study area comprised 1,158 km^2, most of the Tucson Basin. The study area was delineated by an arc with a 19.2-km radius centered on the center of Tucson (here defined as the point midway between the geographic and population centers of the city). This area was bounded to the north and east by the 975 m elevation line in the foothills of the Catalina and Rincon mountains, respectively, to the south by the San Xavier Indian Reservation, and to the west by the Tucson Mountains, including portions of Saguaro National Park (west), and Tucson Mountain Park. Nocturnal rodents were sampled in a restricted portion of this area. Rodent sampling was conducted in an area bounded by Ina Road to the south, Camino de Oeste to the west, Shannon Road to the east, and Camino del Norte to the north (Figure 2).

The Tucson metropolitan population was estimated at >600,000, with an annual growth rate of 23% over the past decade. The metropolitan area is expected to have 900,000 people by the year 2000 (U.S. Dept. of Commerce 1991). Tucson is expanding to the north into the Avra and Oro valleys and toward the Coronado National Forest boundary in the Catalina Mountain foothills, and eastward toward the Saguaro National Park boundary in the Rincon Mountain foothills.

Elevation in the Tucson vicinity ranged from below 640 m along the Santa Cruz River to over 2,770 m at Mt. Lemmon. The Tucson basin receives an average of 28.83 cm of precipitation annually (Mielke 1993), divided between a summer monsoon and a winter rainy season. The mean daily maximum temperature of 38.5 C occurs in July, while the mean daily minimum temperature of 3.4 C occurs in January.

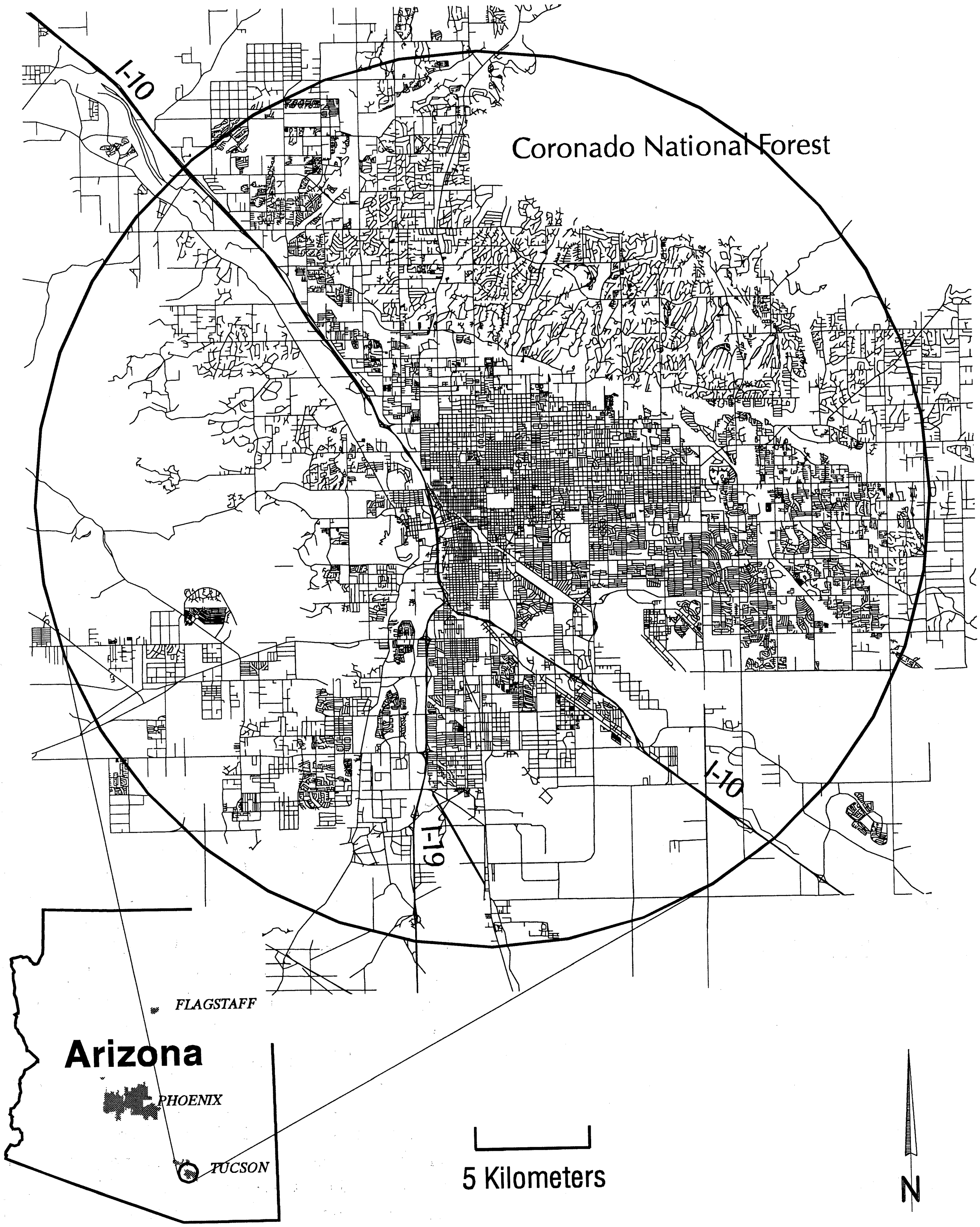


Figure 1. Study area, boundary, and travel routes (shown as a rough indicator of residential density) for bird, lizard, and habitat sampling in Tucson.

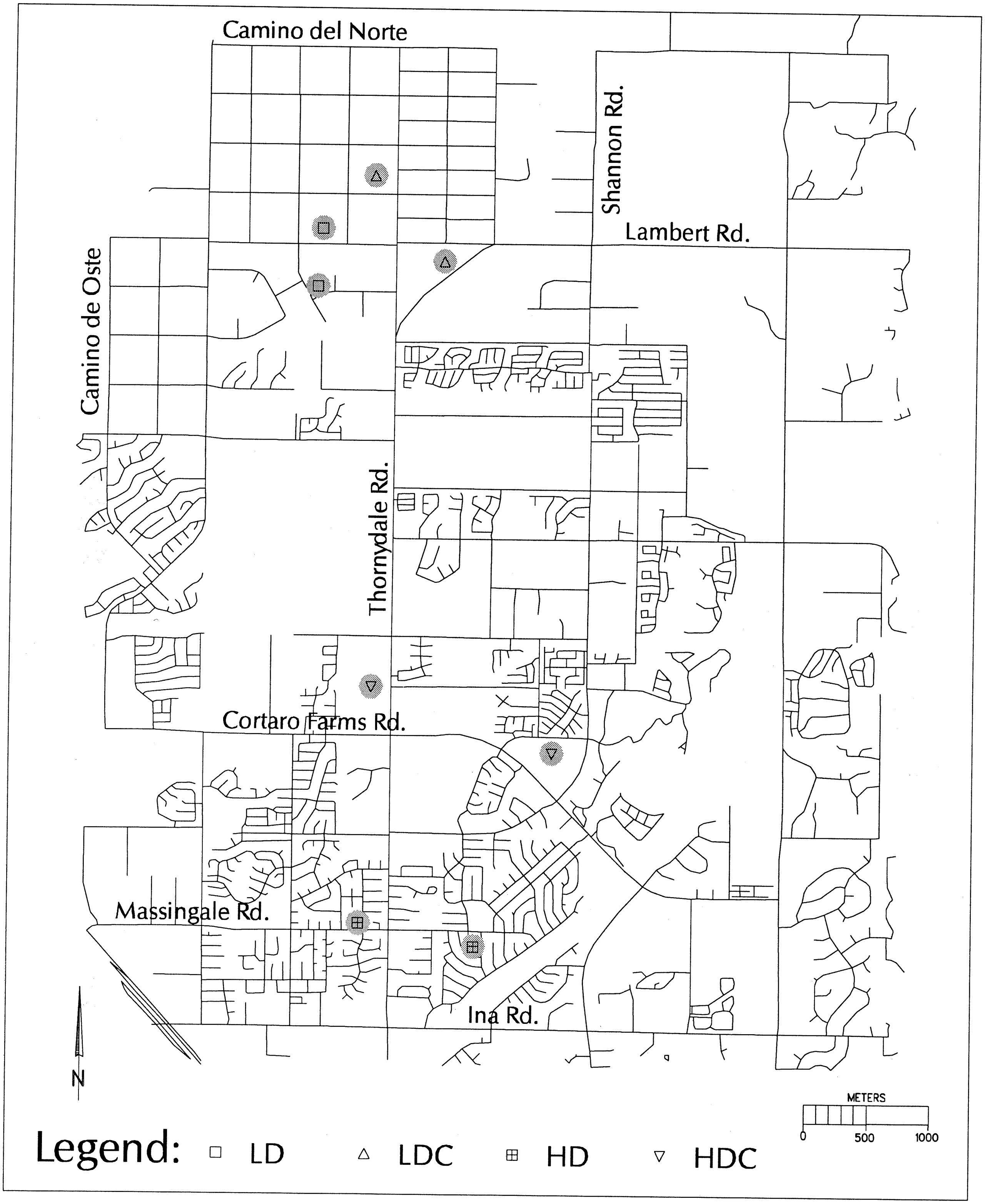
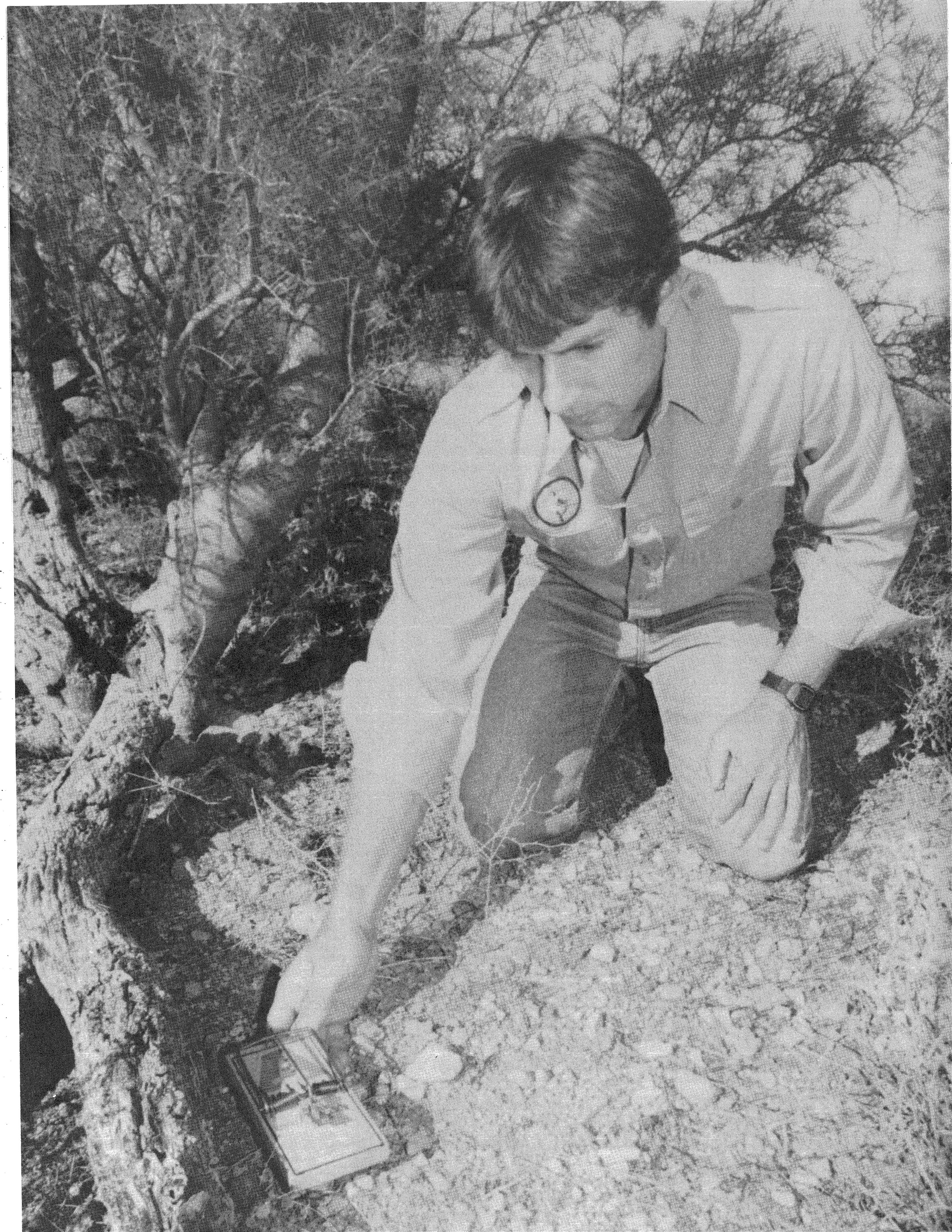


Figure 2. Study area, sites, and travel routes (shown as a rough indicator of residential density) used for nocturnal rodent sampling in Tucson.



METHODS

Study Design

I sampled birds, lizards, and land cover across the entire range of residential development present in the study area. I used a randomized sampling design to minimize biases associated with misrepresentation of habitat availability (Johnson 1980). I used a Geographical Information System (GIS) to generate 33 random points along roads and trails throughout the study area to serve as starting points for 5-km or 5.5-km census routes. I placed a point every 0.5 km along each route as the center of census plots for birds, lizards, and land cover descriptors. This design resulted in 334 census plots within the study area. All routes followed existing roads or trails.

I used the following criteria to avoid clustering census plots, to avoid censusing edges between primary land cover types, and to keep within-plot habitat uniform:

1. Starting points were placed ≥1 km apart;
2. Census plots on adjacent transects had to be ≥200 m apart;
3. Census plots were not placed along 4-lane roads;
4. Census plots were not placed within a 0.5-km buffer zone around Interstates 10 and 19;
5. All census plots were located below 975 m elevation;
6. No census plot was established adjacent to an urban setting with residential densities differing ≥1 housing density class from that of the plot itself (Shaw et al. 1993); and,
7. Commercial and industrial areas were excluded (they were beyond the scope of this study).

In addition, census plots adjacent to and including portions of vacant lots were moved entirely within the lots and as close as possible to the lot center.

I rejected a plot if any of the above 7 criteria were violated. If a plot was rejected, I added 1 to the end of the route. If >2 plots were rejected per route, the entire route was replaced.

Wildlife Data Collection

Breeding Birds. I collected abundance data for breeding birds from March 15 through June 24, 1994. This period coincided with or overlapped peak nesting activity for most species present (Davis and Russell 1990, Corman 1993). For several other species, the census period coincided with the establishment of territories and nest site selection. I did not consider migrant species in this study.

I made no effort to eliminate unmated individuals (floaters) from population estimates, so my estimate of breeding habitat for individual species was likely broader than actually used. Since floaters often occur in marginal habitat, comparisons of bird abundances among habitat types may have artificially inflated probabilities, thus differences would be harder to detect. Since both females and males are likely under similar energetic constraints during the breeding season, and visually distinguishing between sexes of some species is difficult, both sexes were included in counts of abundance at each census plot.

I conducted censuses from 0530 to 1030 Mountain Standard Time (MST) using 50-m fixed-radius, circular plots (Fowler and McGinnes 1973, Verner 1988). This early morning period coincided with the peak in avian daily activity (Robbins 1980). I chose fixed-radius circular plots because accurate distance estimation to singing birds would have been too difficult with the background noises in urban settings. In addition, a stationary observer can detect slow moving birds, cryptic birds, and birds moving into and out of the census plot better than even a slow moving observer (Verner 1988). Moreover, I selected fixed plots over transects because a primary objective was to collect data from independent and homogeneous plots, and area is usually positively correlated with habitat heterogeneity.

I completed 2 census routes each morning, conducting a 5-min. census at each plot. Each plot was visited 4 times. Visits were separated by 3-4 weeks. I ran each route twice in the early morning and twice in the late morning. I ran each route backward once during each time period.

I conducted all censuses and identified all birds by sight or sound. Censuses were temporarily halted during interruptions due to jet, traffic, or human distractions. Censusing was not conducted in rainy (continual, heavy enough to keep pavement wet) or windy (>3 on Beaufort scale) weather.

Wintering Birds. I censused winter resident birds from January 2 through February 20, 1995, using the same methods as described for breeding birds. However, only 306 plots were visited, and 1 visit per plot was made.

Lizards. I surveyed lizards in a systematic subset of 130 census plots from July 12 through September 14, 1994. On each transect I censused plot nos. 1, 4, 7, and 10, except 2 plots on which new home construction had begun since the breeding bird censusing ended. Censusing was begun each morning 1 hour after sunrise and ended 5 hours after sunrise. To account for temperature related differences in activity peaks among lizard species, I divided each morning's census period into 2 2-hour time blocks. Each census plot was visited once per time block. Time blocks were censused back-to-back, and I censused 4 plots in each block each day.

At each plot a 200-m transect centered on the plot center was walked at a steady pace (50 m/5 to 6 minutes). At plots occurring on roads, 100-m transects were walked on each side of the road and summed. At non-road plots, a straight 200-m transect was walked. This transect was centered on the plot center and followed the existing trail. Only lizards within 15 m of the transect were included. Once a lizard was spotted, time spent identifying it (if necessary) was not included in the elapsed census time. Interruptions were treated in the same manner as in bird censusing. Transect route road surfaces were excluded from surveys, and an equal (non) likelihood of lizards crossing roads and being re-surveyed was assumed at each transect.

Nocturnal Rodents. I collected abundance data for nocturnal rodents from 8 50-trap lines of snap traps from October 3-5, 1994. I limited the nocturnal rodent component of this study to a comparison of the assemblages present at 2 pre-defined levels of housing density. I placed 2 trap lines in low density housing (0.5 houses/ha) and 2 in high density housing (7.5 houses/ha). Each housing treatment was adjacent to a $\geq$10 ha control block of undeveloped habitat which contained native vegetation (0 house density sites).

For each of the 4 trap lines placed within residential areas, I placed a control trap line near the center of the native habitat block. This arrangement resulted in 4 treatments: 1) low density, 2) low-density control, 3) high density, and 4) high-density control. Paired study sites were similar with respect to vegetation types, proximity to washes, and elevation. Native habitat fragments were no more than twice as long as wide to minimize edge effects, and I located all of the sampling sites in an area undergoing rapid residential development.

I placed 2 traps every 10 m, totalling 250 m trapping distance per line. In low-density sites, traps were placed 2 m from the edge of roads. In high-density sites, traps were placed along the edges of alley-ways in areas containing few solid block walls which might restrict small mammal movement. Traps in control sites were set at the same spacing as used at residential sites. Mouse traps (Museum Special and Victor) were set at a 3:1 ratio to rat traps (Victor). Traps were baited with a rolled oat/peanut butter mixture, set at dusk of each night of sampling, and collected shortly after dawn the following day.

Land Cover Quantification

The focus of habitat quantification in this study was: 1) to measure the percent of land cover that was altered from its native state, and 2) to identify the degree to which it was altered. To describe the existing land cover types and arrangements, I measured 33 habitat variables from aerial photographs and adjusted them with field reconnaissance (Table 1). I selected or modified several variables from Stenberg (1988) and Shaw et al. (1993) to be more compatible with other studies. Also, several variables were measured only for descriptive purposes and were not used in statistical analyses.

Primary land cover type was recorded for each census plot as either lower Sonoran (*Larrea tridentata* dominant), upper Sonoran (*Cercidium* spp.-*Carnegiea gigantea* dominant), or non-native (no land left in a native vegetative state, all vegetative cover consisting of ornamental plantings or weedy growth).

I determined percent area in each land cover type from measurements of aerial photographs and from field verification of land cover category assignments. I centered an acetate circle representing a 100-m radius (3.1 ha) circular plot on each census plot. The acetate overlay contained a 3.6-m dot grid on which I traced polygons delimiting each land cover type present. A 100-m radius plot was chosen to better estimate the actual value for the habitat cover types at each plot, because wildlife were not restricted by the boundaries of the plots. I then calculated the percent area of each polygon and summed these within each cover type.

Table 1. Codes, means, and ranges for 33 habitat descriptors in Tucson. % indicates proportions of ground surface covered.

Variable	Code	Mean	SE	Range
House density/ha	HDEN	3.29	0.21	19.8
% house	PCTH	8.01	0.48	43.7
% apartments/businesses	PCTA	1.54	0.25	28.6
% paved or graded	PCTP	18.30	0.56	62.2
% exotic tree canopy	EXOT	0.47	0.08	13.0
% urban treed	URBT	0.41	0.14	35.2
% urban treed native	URTN	0.13	0.08	19.1
% urban treed mixed	URTM	0.13	0.06	14.3
% urban treed exotic	URTE	0.16	0.11	35.2
% urban savannah	URBS	1.28	0.27	54.2
% urban savannah native	URSN	0.37	0.14	37.6
% urban savannah mixed	URSM	0.27	0.09	23.0
% urban savannah exotic	URSE	0.64	0.21	54.2
% urban open	URBO	23.80	1.28	80.0
% urban open native	URON	2.96	0.48	62.5
% urban open mixed	UROM	4.48	0.71	79.7
% urban open exotic	UROE	16.36	1.22	80.0
% native veg = (LSV+USV+MEBO)	NATV	41.73	1.89	99.5
Lower Sonoran Vegetation	LSV			
% visibly sparse	LSVS	1.44	0.35	53.5
% normal abundance	LSNA	10.64	1.35	95.0
% over abundant	LSOA	0.14	0.09	28.6
Upper Sonoran Vegetation	USV			
% visibly sparse	USVS	2.02	0.40	63.7
% normal abundance	USNA	26.41	1.80	99.5
% over abundant	USOA	0.08	0.06	18.7
% mesquite bosque	MEBO	1.00	0.38	75.7
% open water	OW	0.15	0.02	2.3
% disturbed riparian	RIPD	0.35	0.10	17.9
% undisturbed riparian	RIPU	3.90	0.47	65.0
plot heterogeneity	HET	3.06	0.05	5.0
distance from mainland (m)	DISM	3,298	175	10,728
distance from patch (m)	DISP	290	26	2,822
distance from riparian (m)	DISR	924	67	5,040

Statistical Analysis

Habitat Variables. I defined associations between 15 of the habitat variables using Spearman ranked correlation analysis (Zar 1984, Statsoft 1995). I was restricted to 15 variables because several of the original variables were intended for descriptive purposes only and several others were not abundant enough to include. All 15 variables were retained for ensuing correlation analyses despite potential inter-correlations because I wanted to identify the association each habitat variable had with species abundances. Inter-correlated variables were not allowed to enter predictive models. The alpha level for this and all statistical tests was set at $P \leq 0.05$.

Breeding Birds. Bird species and community variables generated at each census plot were: abundance of each species (averaged over the 4 visits), total abundance, and species richness for each of the following 3 groups of resident breeding birds:

1. Non-native species;
2. Native species; and,
3. A guild comprised of birds that were insectivorous, tree or shrub foliage gleaners, and shrub nesters.

I selected feeding and nesting substrates as guild delineators to remove the subjectivity in guild selection that has been a major criticism of guild usage (see Holmes et al. 1979, Jaksic 1981, Johnson 1981, Severinghaus 1981, Verner 1984).

I determined habitat associations for birds by Gamma correlation analysis of abundances of individual species with habitat variables. Fifteen ranked habitat descriptors were included with ranked abundances of 21 species of birds which met sample size requirements. I chose Gamma correlations because there were many ties in the bird abundance data, and this statistic takes ties into account, whereas Spearman and Kendall Tau coefficients do not (Statsoft 1995). Significant correlations with coefficients ≥ 0.5 were retained.

I then identified the relationship between each habitat variable and the bird species it correlated with by graphing mean bird species abundance against percent (or distance) classes of each habitat variable. I created classes that were meaningful to land managers and which evenly distributed data among groups.

I used correlation and forward stepwise multiple regression to develop predictive habitat models for the 3 bird groups (Statsoft 1995). I used Spearman ranked correlation to determine associations between the bird community descriptors and habitat variables. Habitat variables that were correlated with species richness of each of the 3 bird groups were subjected to stepwise multiple regression analysis.

I examined 4 residual diagnostics for each regression analysis. I plotted and removed outliers, which were defined as those cases whose standardized residuals were >2 standard deviations from the mean residual value. Second, I evaluated Cook's distance (Cook 1977) for each case. Cook's distance is a measure of the affect a case has on the value of the regression coefficient and should be roughly equal for all cases. Third, I examined the Durbin-Watson statistic (Durbin and Watson 1951), which identifies whether cases are independent by analyzing the degree of correlation between adjacent residuals. Last, I reviewed both normal probability plots of residuals and plots of predicted versus residual scores. These indicate if residuals are normally distributed, and test the assumption of a linear relationship between the independent and dependent variables, respectively.

I verified the predictive ability of each regression equation by cross validation (Neter et al. 1990). I randomly split the original data into 2 subsets. The equation for the predictive model was generated using 80% of the data, then this model was used to predict values for each case in the 20% subset. I determined the mean squared prediction error (MSPR) and compared it to the error mean square (MSE) of the original data subset. The closeness of these values indicated the extent to which the MSE was biased and gave an indication of how accurately the model should predict the value of the response variable using new data.

In addition, I assessed the similarity of slopes in the 2 data subsets by comparing the residual scores between them using an independent samples t-test. If the slope of the second data subset differed from the first, then the scatter of data points would have had a different arrangement than that of the first; i.e., the residual values of the second subset would deviate more from the predicted slope than the residual values for the model building data set.

Wintering Birds. Variables generated for winter bird:habitat analysis were the same as those generated for breeding birds. I subjected abundances of 8 ranked bird species and 15 habitat variables to Gamma correlation analysis. I then identified the relationship between each habitat variable and the bird species it correlated with by graphing mean bird species abundance against each habitat variable.

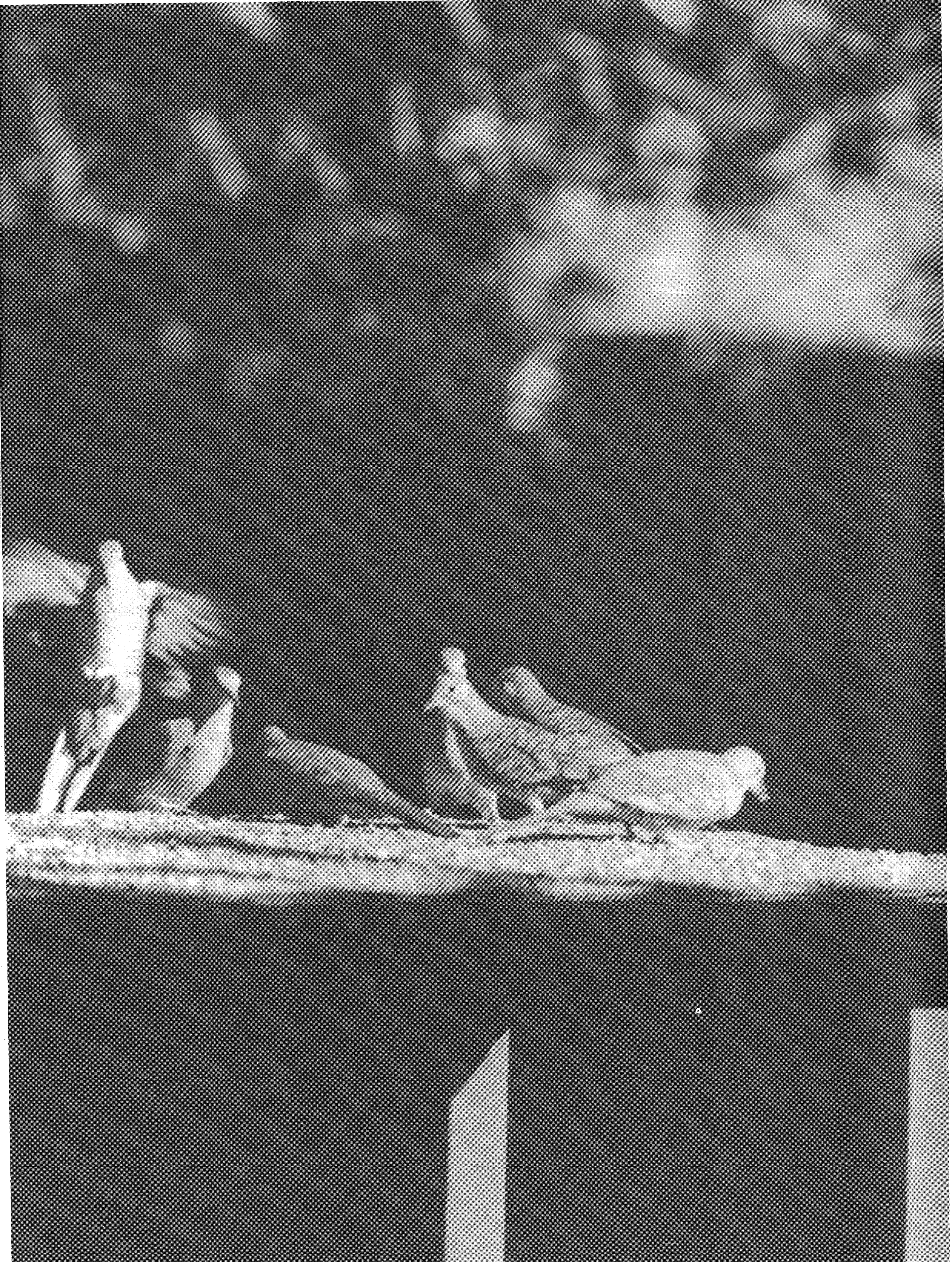
Lizards. Variables describing the lizard community at each plot were: abundance of each species, species richness, and total abundance, summed across all species. For each species at each plot, the abundance value was calculated as the mean of the 2 visits.

Ranked lizard species abundances and habitat variables were subjected to Gamma correlation analysis. I then plotted mean lizard species abundance against classes of each habitat variable. Since the lizard sample was smaller than the bird sample, I chose a subset of 5 of the 15 habitat variables used for the bird community analysis and the 4 lizard species that met sample size requirements.

I used correlation and forward stepwise multiple regression analysis to develop 2 predictive models associating species richness (all species inclusive) and total abundance with the 5 habitat variables. I treated outliers and diagnostics the same as for breeding birds. The lizard data set was not large enough to cross validate the model.

Wildlife Community Descriptors. I used Spearman ranked correlation analyses to compare the association of 3 parameters of the bird and lizard communities across the urban gradient. Species richness, total abundance, and (modified Hill's [1973]) evenness ratio $F_{1,0}$; Alatalo 1981), for the 5 bird groups (breeding native, non-native, indicator guild, wintering native and non-native) and for lizards were correlated with the habitat variables that loaded into each group's predictive model, and with a simple estimator of plot heterogeneity. Habitat variables that loaded with each breeding bird group were used for associated wintering bird groups. Heterogeneity was the number of major land cover types present at each plot.

Nocturnal Rodents. I compared the abundance of each species, species richness, and total abundance between the treatments and controls in a 2 x 2 contingency table using a 2-tailed Fisher's exact test (Statsoft 1995). I also performed Post-hoc tests via Chi-square subdivision to determine if >1 cell contained significantly different values of any of the dependent variables (Zar 1984). Where expected values in the subdivision test did not meet the test sample size requirements, I employed a Yates correction (Wilkinson 1990, Statsoft 1995). The total abundance data set contained large enough sample sizes to approximate a normal Chi-square distribution, so I tested changes in total abundance with the Chi-square statistic instead of Fisher's exact test (Zar 1984).



RESULTS

Land Cover Associations

Native vegetation (combined lower and upper Sonoran, and mesquite bosque cover types) was the most common land cover type encountered in the census plots, and comprised almost 42% of all land sampled (Table 1). This does not represent the actual amount of native land cover remaining in Tucson, because the study area boundary extended beyond the developed areas. The amount of native vegetation per plot ranged from 0 to 99.5% of total ground cover. Over 28% of this land was upper Sonoran habitat, of which 2% was visibly thinned or degraded by human activity. Another 12.3% was lower Sonoran vegetation, with 1% thinned or degraded by human activity. Less than 0.1% of all native land cover sampled was classified as visibly thickened or enhanced by human activity. One percent of all native vegetation cover sampled was mesquite bosque. Paved or graded land comprised 18.3% of all land sampled, and ranged from 0 to 62.2% of the total ground cover within census plots.

Yards that I classified as urban open were the most common urban land cover type, comprising 23.8% of all land sampled. The range of values in the plots for urban open areas was from 0 to 80.0%. Most urban open land was predominantly non-native vegetation (16.4%), whereas only 3% was predominantly native, and 4.5% was a mixture of both native and non-native vegetation. Both urban treed areas (containing >60% tree canopy closure) and urban savannahs (30-60% canopy closure) were rare, comprising only 0.4% and 1.3% respectively of the total area sampled.

The average number of houses/ha was 3.3 (1.3/ac), and houses covered an average of 8.0% of all land within plots. Number of houses ranged from 0 to 19.8 per ha (7.9/ac) and covered a range from 0 to 43.7 % of the land within plots. Apartment buildings and small businesses covered an average of 1.5% of land in plots, ranging from 0-28.6% of land cover measured. Undisturbed washes comprised an average of 3.9%, and disturbed washes comprised an average of 0.3% of all land cover. The percent of ground covered by undisturbed washes ranged from 0-65%, disturbed wash cover ranged from 0-17.9%.

Distance of census plots from mainland areas ranged from 0-10.7 km and averaged 3.3 km. The distance from >1 ha undeveloped patches of land ranged from 0-2.8 km and averaged only 291 m. The distance of points from undisturbed riparian zones averaged 925 m and ranged from 0-5.0 km. Sampling plots contained an average of 3 distinct land cover types each, and ranged from only 1 type to 6 distinct types present. Several of the habitat descriptors were inter-correlated (Table 2).

Wildlife Data Results

Breeding Birds. Fifty-eight species of birds known to breed within the study area were detected during spring censusing (Appendix A). The most abundant species were the house sparrow (*Passer domesticus*, n = 2,031), mourning dove (*Zenaida macroura*, n = 996), and house finch (*Carpodacus mexicanus*, n = 848). The most wide-spread species were the mourning dove, house finch, and cactus wren (*Campylorhynchus brunneicapillus*), which occurred in 315, 315, and 259 of the 334 total plots, respectively. Species richness at each census plot ranged from 4-18, with a mean of 11.8 ± 0.15 (SE). Total number of individuals per plot ranged from 5.5-68, and averaged 24.9 ± 0.42. Four species of non-native birds were detected during censusing, house sparrow, European starling (*Sturnus vulgris*), rock dove (*Columba livia*), and Inca dove (*Columbina inca*). I included the Inca dove in the non-native bird group because it is a relatively recent arrival (circa 1870) into the Tucson area, and has a history of close association with urbanization in both Arizona and throughout its original range in Mexico.

Wintering Birds. Forty-two species of birds were encountered during the winter census period (Appendix B). Three wintering species were encountered that were not encountered during breeding season censusing: black-chinned sparrow (*Spizella atrogularis*), ruby-crowned kinglet (*Regulus calendula*), and black-throated gray warbler (*Dendroica nigrescens*). The most abundant species encountered were the same as those in the breeding season censuses; the house sparrow (n = 1,227), mourning dove (n = 1,217), and the house finch (n = 385). The same 3 species were also the most wide-spread; mourning doves were present in 183 plots, house sparrows were present in 164 plots, and house finches were present in 123 of the 306 plots that were visited. Species richness ranged from 0-11, with a mean of 4.5 ± 0.14. Total number of individuals per plot ranged from 0-132, with a mean of 15.3 ± 1.10. Four non-native species were detected during winter censusing, house sparrows, European starlings, rock doves, and Inca doves.

Table 2. Spearman correlations among 15 habitat variables measured in Tucson. See Table 1 for full variable names.

	HDEN	PCTA	PCTP	URBT	URBS	URON
HDEN	-					
PCTA	0.35*	-				
PCTP	0.58*	0.37*	-			
URBT	0.03	-0.10	-0.03	-		
URBS	0.07	-0.02	-0.01	0.29*	-	
URON	0.00	-0.17*	-0.02	-0.03	0.13*	-
UROM	0.08	0.07	0.10	0.05	0.08	0.13*
UROE	0.72*	0.26*	0.45*	-0.07	-0.09	-0.18*
LSV	-0.26*	-0.08	-0.12*	-0.01	-0.11*	0.01
USV	-0.56*	-0.30*	-0.44*	0.03	0.03	0.06
RIPU	-0.42*	-0.16*	-0.32*	-0.04	-0.06	0.05
HET	-0.01	-0.04	0.02	0.17*	0.16*	0.25*
DISM	0.60*	0.34*	0.39*	-0.01	0.07	0.01
DISP	0.84*	0.38*	0.54*	0.07	0.13*	-0.02
DISR	0.57*	0.36*	0.44*	-0.02	0.00	-0.20*

	UROM	UROE	LSV	USV	RIPU	HET
UROM	-					
UROE	-0.26*	-				
LSV	-0.01	-0.20*	-			
USV	-0.06	-0.47*	-0.45*	-		
RIPU	-0.05	-0.36*	-0.12*	0.41*	-	
HET	0.19*	-0.09	-0.03	0.12*	0.11*	-
DISM	0.12*	0.51*	-0.06	-0.51*	-0.41*	0.00
DISP	0.18*	0.62*	-0.23*	-0.57*	-0.43*	0.00
DISM	0.00	0.54*	0.05	-0.60*	-0.59*	-0.21*

* = significant at $P \leq 0.05$.

Table 2. (continued) Spearman correlations among 15 habitat variables measured in Tucson.

	DISM	DISP	DISR
DISM	-		
DISP	0.68*	-	
DISR	0.62*	0.67*	-

* = significant at $P \leq 0.05$.

Lizards. I encountered 9 species of lizards during censusing (Appendix C). Whiptail lizards (*Cnemidophorus* spp.) were the most abundant, totalling 122 individuals, in part because members of this genus were not identified to species. The tree lizard (*Urosaurus ornatus*) was the most abundant single species observed (n = 33). The least abundant species I observed were side-blotched (*Uta Stansburiana*, n = 1) and regal horned lizards (*Phrynosoma solare*, n = 1). Whiptail lizards were also the most widely distributed lizards seen, occurring in 67 of 130 plots, followed by desert spiny lizards (*Sceloporus magister*) which were present in 40 plots. Side-blotched and regal horned lizards were the least widely distributed lizards observed. Lizard species richness ranged from 0-5 species, with a mean of 1.4 ± 0.09 species per plot. Lizard plots averaged 1.7 ± 0.15 individuals and ranged from 0-9 individuals.

Nocturnal Rodents. One hundred forty-four individuals representing 5 species of nocturnal rodents were trapped (Appendix D). The most abundant species I detected was the desert pocket mouse (*Chaetodipus penicilatus*), with 45 individuals trapped. Least abundant and least wide-spread was the house mouse, of which 4 individuals occurred at 2 of the 8 sites. The most wide-spread rodents were the desert pocket mouse, Merriam's kangaroo rat (*Dipodomys merriami*), and the white-throated wood rat (*Neotoma albigula*), each of which was present at 6 of the 8 sites.

Wildlife - Land Cover Relationships

Breeding Birds. Distance from undeveloped patches (DISP, Table 1; see Appendix E for complete variable descriptions) correlated with total abundances for 9 (43%) of the bird species (Table 3, Fig. 3). Distance from patch correlated positively with the 4 non-native species and northern mockingbirds (*Mimus polyglottos*) while verdins (*Psaltriparus minimus*), black-tailed gnatcatchers (*Polioptila melanura*), black-throated sparrows (*Amphispiza bilineata*), and northern flickers (*Colaptes auratus*) were all negatively correlated with distance from patches. House density (HDEN) correlated with 8 (38%) of the bird species. House density correlated positively with the 4 non-native species and northern mockingbirds and negatively with verdins, black-tailed gnatcatchers, and black-throated sparrows. Percent area covered by upper Sonoran vegetation (USV), percent area covered by apartments and small business buildings (PCTA), and washes in their natural, undisturbed state (RIPU) each correlated with 7 (33%) of the bird species. Upper Sonoran vegetation was positively correlated with black-tailed gnatcatchers and negatively correlated with the 4 non-native species, northern mockingbirds, and great-tailed grackles (*Quiscalus mexicanus*). Percent area covered by apartments and small business buildings correlated positively with house sparrows, and rock doves and negatively with Gambel's quail (*Callipepla gambelii*), pyrrhuloxias (*Cardinalis sinuatus*), black-tailed gnatcatchers, black-throated sparrows, and northern flickers. Undisturbed riparian correlated positively with pyrrhuloxias and negatively with the 4 non-native species, northern mockingbirds, and great-tailed grackles. The percent urban-open exotic land area (comprised of ≥60 percent non-native tree and shrub composition, and ≤30 percent total tree canopy closure [UROE]) correlated with 6 (29%) of the 21 bird species. Percent urban-open exotic correlated positively with house sparrows, rock doves, and Inca doves and negatively with verdins, black-tailed gnatcatchers, and black-throated sparrows. Distance to mainland areas (DISM) correlated with 3 (14%) of the bird species. Distance from mainland correlated positively with house sparrows and rock doves and negatively with black-throated sparrows. Distance from undisturbed washes (DISR) and the percent (urban savannah land covered by vegetated areas disturbed from a natural state having 30-60% tree canopy closure [URBS]) each correlated with 2 (10%) of the bird species. Distance from riparian correlated positively with Inca doves and rock doves. Percent urban savannah correlated positively with white-winged doves (*Zenaida asiatica*) and negatively with black-throated

Table 3. Gamma correlations between 21 breeding birds and 15 habitat variables in Tucson. See Appendix A for full species names.

	HDEN	PCTA	PCTP	URBT	URBS	URON	UROM	UROE
MODO	0.31*	0.00	0.24*	0.36*	0.34*	0.37*	0.30*	0.18*
HOFI	0.44*	0.23*	0.28*	-0.02	0.32*	0.10	0.24*	0.35*
CAWR	-0.22*	-0.40*	-0.09*	0.05	0.14	0.34*	0.19*	-0.29*
CBTH	-0.15*	-0.24*	-0.09*	0.04	0.16*	0.30*	0.03	-0.17*
HOSP	0.73*	0.54*	0.43*	0.15	0.19*	-0.03	0.15*	0.61*
VERD	-0.54*	-0.41*	-0.30*	0.07	0.18*	0.25*	0.09*	-0.56*
WWDO	0.26*	0.06	0.06	0.29*	0.52*	0.24*	0.18*	0.14*
GIWO	-0.03	-0.11	-0.06	0.08	0.24*	0.09	0.17*	-0.12*
GAQU	-0.31*	-0.54*	-0.17*	0.41*	0.32*	0.40*	0.26*	-0.40*
INDO	0.70*	0.48*	0.43*	0.22	0.24*	-0.26*	0.01	0.59*
NOMO	0.50*	0.42*	0.36*	0.33*	0.25*	-0.11	0.19*	0.45*
EUST	0.53*	0.47*	0.37*	0.17	0.16	-0.05	0.26*	0.45*
PYRR	-0.44*	-0.62*	-0.20*	-0.59*	-0.01	-0.33*	-0.09	-0.45*
BTGN	-0.78*	-0.77*	-0.48*	-0.22	-0.23*	-0.24*	-0.38*	-0.70*
BTSP	-0.79*	-0.70*	-0.52*	-0.43	-0.59*	-0.21*	-0.72*	-0.63*
NOCA	0.04	-0.19	0.01	0.43*	0.25*	0.39*	0.41*	-0.31*
GTGR	0.47*	0.28*	0.33*	0.33*	0.04	-0.09	-0.08	0.38*
NOFL	-0.48*	-0.52*	-0.34*	-0.28	-0.04	0.06	-0.11	-0.38*
BHCO	-0.30*	-0.30*	-0.19*	-0.28	0.11	0.19*	0.09	-0.35*
RODO	0.58*	0.63*	0.36*	0.02	-0.24	-0.57*	-0.10	0.61*
ANHU	0.22*	0.20*	0.06	-0.45	0.21	0.22*	0.15	0.07

	LSV	USV	RIPU	HET	DISM	DISP	DISR
MODO	-0.13*	-0.15*	-0.15*	0.23*	0.25*	0.31*	0.05
HOFI	-0.26*	-0.22*	-0.30*	0.11*	0.34*	0.42*	0.21*
CAWR	-0.03	0.30*	0.25*	0.18*	-0.25*	-0.29*	-0.29*
CBTH	0.06	0.24*	0.28*	0.21*	-0.13*	-0.19*	-0.23*
HOSP	-0.22*	-0.60*	-0.53*	0.06	0.50*	0.70*	0.46*
VERD	0.13*	0.44*	0.42*	0.18*	-0.33*	-0.53*	-0.43*
WWDO	-0.51*	0.03	0.00	0.25*	0.10*	0.26*	0.02
GIWO	-0.44*	0.28*	0.38*	0.25*	-0.15*	-0.02	-0.19*
GAQU	-0.05	0.40*	0.32*	0.34*	-0.29*	-0.34*	-0.40*
INDO	-0.22*	-0.63*	-0.66*	0.01	0.49*	0.63*	0.51*
NOMO	-0.21*	-0.51*	-0.65*	-0.08	0.44*	0.51*	0.43*
EUST	-0.18*	-0.53*	-0.53*	0.03	0.43*	0.61*	0.42*
PYRR	0.01	0.39*	0.50*	0.15*	-0.33*	-0.45*	-0.45*
BTGN	0.14	0.55*	0.46*	-0.12	-0.48*	-0.79*	-0.46*
BTSP	0.44*	0.38*	0.40*	-0.23*	-0.52*	-0.82*	-0.39*
NOCA	-0.30*	0.18*	0.05	0.40*	-0.09	0.06	-0.19*
GTGR	-0.18	-0.51*	-0.62*	-0.04	0.32*	0.43*	0.33*
NOFL	0.05	0.40*	0.33*	0.01	-0.49*	-0.56*	-0.33*
BHCO	-0.21*	0.39*	0.32*	0.01	-0.16*	-0.28*	-0.29*
RODO	-0.22*	-0.74*	-0.84*	-0.26*	0.67*	0.68*	0.74*
ANHU	-0.31*	-0.17*	-0.32*	0.08	0.27*	0.23*	0.08

* = significant at $P \leq 0.05$.

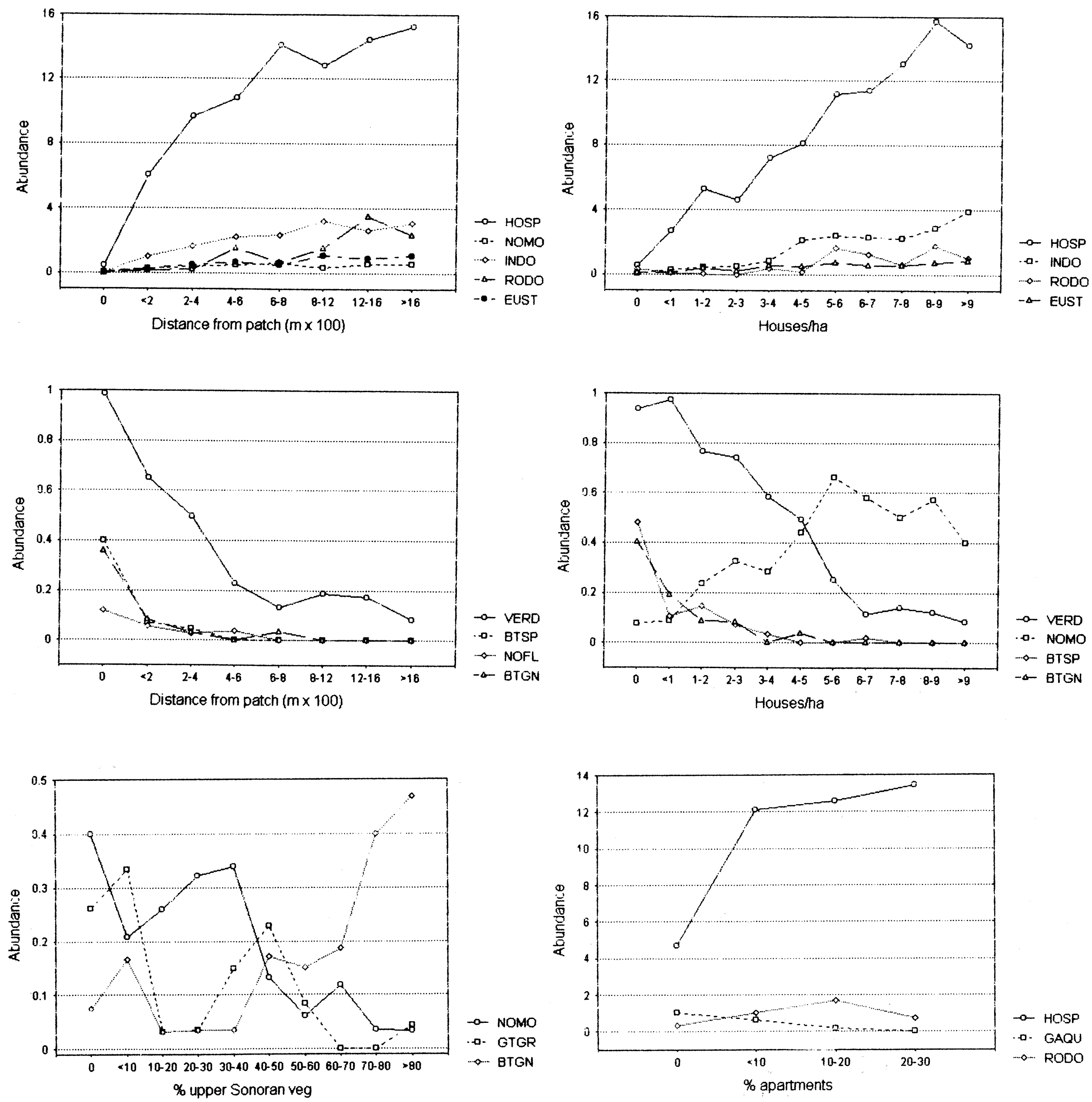


Figure 3. Breeding bird abundance trends over classes of habitat variables in Tucson in 1994.

HOSP = house sparrow
NOMO = northern mockingbird
BTGN = black-tailed gnatcatcher
INDO = Inca dove
RODO = rock dove
EUST = European starling
VERD = verdin

BTSP = black-throated sparrow
NOFL = northern flicker
GTGR = great-tailed grackle
GAQU = Gambel's quail
PYRR = pyrrhuloxia
WWDO = white-winged dove

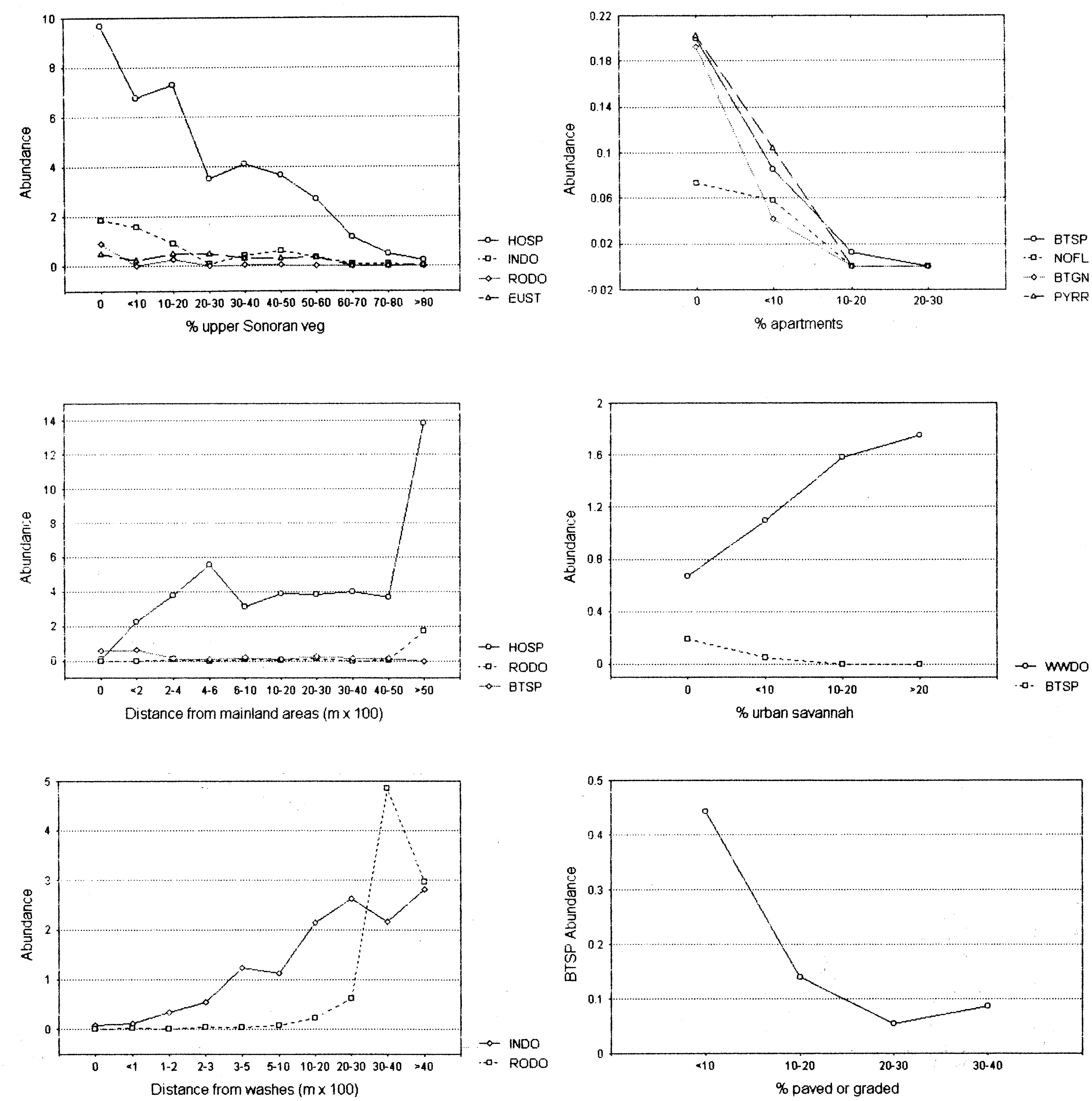


Figure 3. (continued) Breeding bird abundance trends over classes of habitat variables in Tucson in 1994.

HOSP = house sparrow
NOMO = northern mockingbird
BTGN = black-tailed gnatcatcher
INDO = Inca dove
RODO = rock dove
EUST = European starling
VERD = verdin

BTSP = black-throated sparrow
NOFL = northern flicker
GTGR = great-tailed grackle
GAQU = Gambel's quail
PYRR = pyrrhuloxia
WWDO = white-winged dove

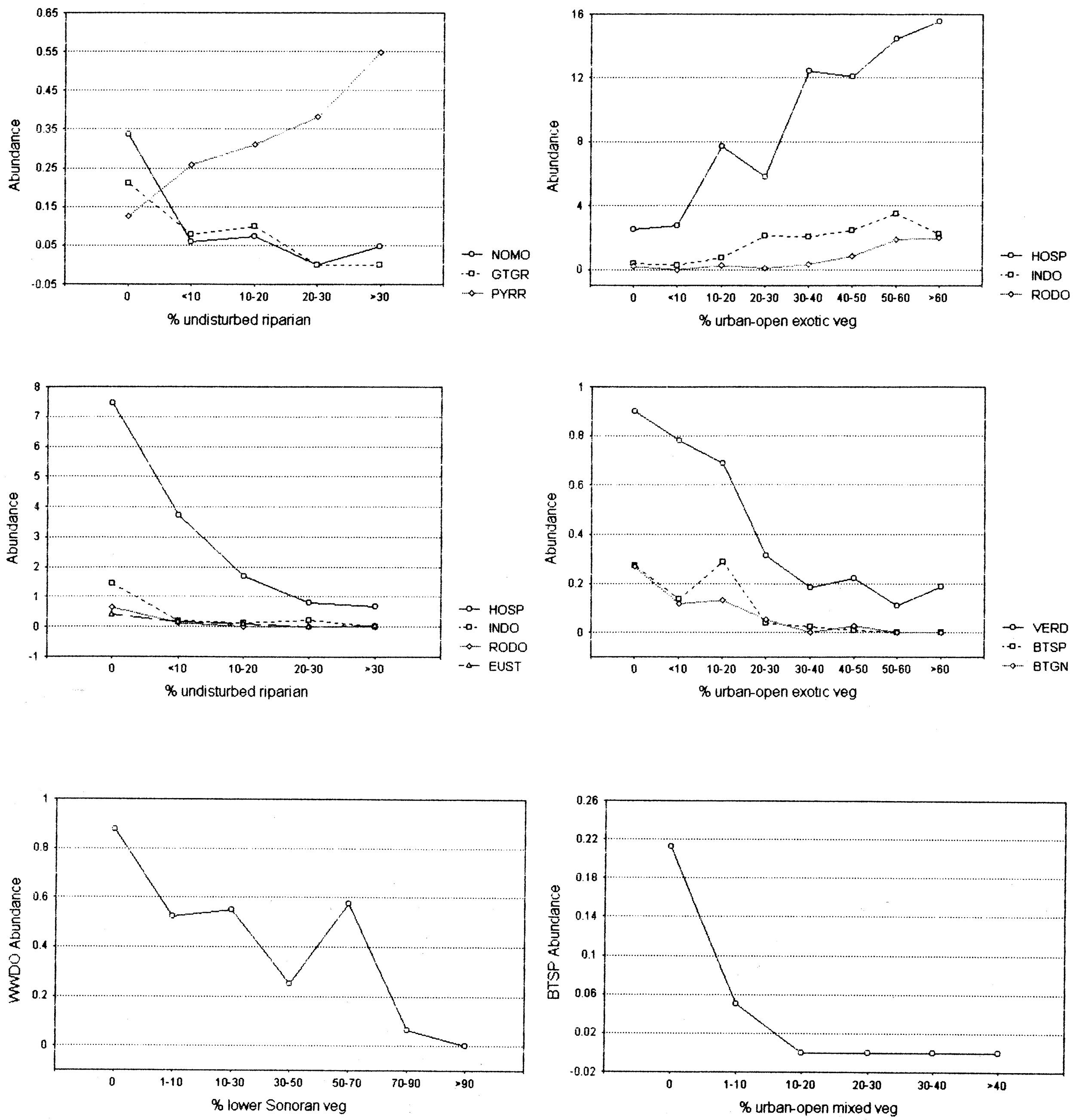


Figure 3. (continued) Breeding bird abundance trends over classes of habitat variables in Tucson in 1994.

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GAQU = Gambel's quail
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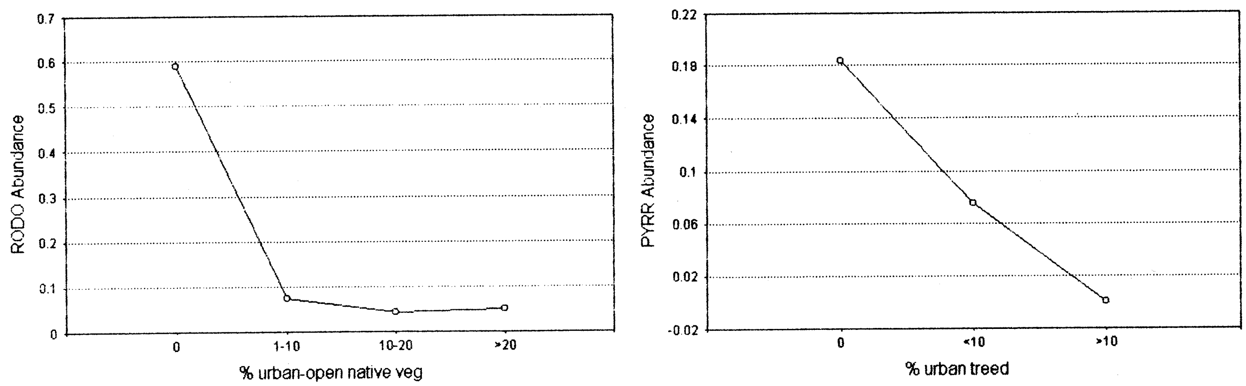

Figure 3. (continued) Breeding bird abundance trends over classes of habitat variables in Tucson in 1994.

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BTGN = black-tailed gnatcatcher
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RODO = rock dove
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BTSP = black-throated sparrow
NOFL = northern flicker
GTGR = great-tailed grackle
GAQU= Gambel's quail
PYRR = pyrrhuloxia
WWDO = white-winged dove

sparrows. Five habitat variables correlated with 1 bird species each. Percent area paved or graded (PCTP) and urban-open mixed land (areas disturbed from a natural state containing <30% tree canopy closure and comprised of 30-60% of both native and non-native tree species [UROM]) both correlated negatively with black-throated sparrows. The percent urban treed land (covered by vegetated areas disturbed from a natural state and having >60% tree canopy closure [URBT]) correlated negatively with pyrrhuloxias. Urban-open native land (disturbed from a natural state and having both <30% tree canopy closure and >60% native species comprising the trees and shrubs present [URON]) correlated negatively with rock doves. Finally, area covered by naturally occurring lower Sonoran vegetation (LSV) was negatively correlated with white-winged doves (*Zenaida asiatica*). Habitat heterogeneity (HET) did not correlate with any breeding bird species.

Wintering Birds. Distance from patch correlated with 3 (38%) of the bird species included in the analysis (Table 4, Fig. 4). Distance from patch correlated positively with house sparrows and Inca doves, and negatively with verdins. House density, percent apartments/businesses, percent urban-open exotic, upper Sonoran vegetation, and percent undisturbed riparian each correlated with 2 (25%) of the 8 wintering bird species. House density and percent urban-open exotic both correlated positively with house sparrows and Inca doves. Upper Sonoran vegetation and percent undisturbed riparian both correlated negatively with house sparrows and Inca doves. Percent apartments/businesses correlated positively with Inca doves and negatively with verdins. Distance from riparian correlated positively with Inca doves. Percent paved or graded, percent urban treed, percent urban savannah, percent urban open native, percent urban open mixed, lower Sonoran vegetation, and distance from mainland did not correlate with any wintering bird species.

Table 4. Gamma correlations between 8 wintering birds and 15 habitat variables in Tucson. See Appendix B for full species names.

	HDEN	PCTA	PCTP	URBT	URBS	URON	UROM	UROE
MODO	0.41*	0.05	0.30*	0.36*	0.00	0.25*	0.21*	0.33*
HOFI	0.33*	0.11	0.20*	0.13	0.32*	0.05	0.09	0.23*
HOSP	0.65*	0.48*	0.39*	0.23	0.06	0.00	0.19*	0.53*
CAWR	-0.05	-0.48*	0.01	0.25	0.19	0.39*	0.13	-0.09
INDO	0.68*	0.53*	0.48*	-0.26	-0.01	-0.38*	-0.19	0.58*
GIWO	0.11	-0.14	0.02	-0.05	0.43*	0.30*	0.14	0.01
CBTH	0.00	-0.41*	0.02	0.23	0.17	0.14	0.16	-0.10
VERD	-0.49*	-0.61*	-0.22*	0.11	-0.04	0.01	0.10	-0.49*

	LSV	USV	RIPU	HET	DISM	DISP	DISR
MODO	-0.17*	-0.27*	-0.29*	0.18*	0.29*	0.40*	0.20*
HOFI	-0.22*	-0.24*	-0.19*	0.09	0.20*	0.32*	0.23*
HOSP	-0.24*	-0.57*	-0.55*	0.03	0.38*	0.59*	0.39*
CAWR	-0.15	0.16*	0.11	0.16*	-0.17*	-0.20	-0.19*
INDO	-0.07	-0.77*	-0.85*	-0.15*	0.42*	0.60*	0.56*
GIWO	-0.49*	0.14	0.04	0.03	-0.01	0.14*	0.00
CBTH	-0.02	0.10	0.16	0.32*	-0.03	-0.03	-0.16*
VERD	0.01	0.42*	0.33*	0.17*	-0.42*	-0.53*	-0.39*

* = significant at $P \leq 0.05$.

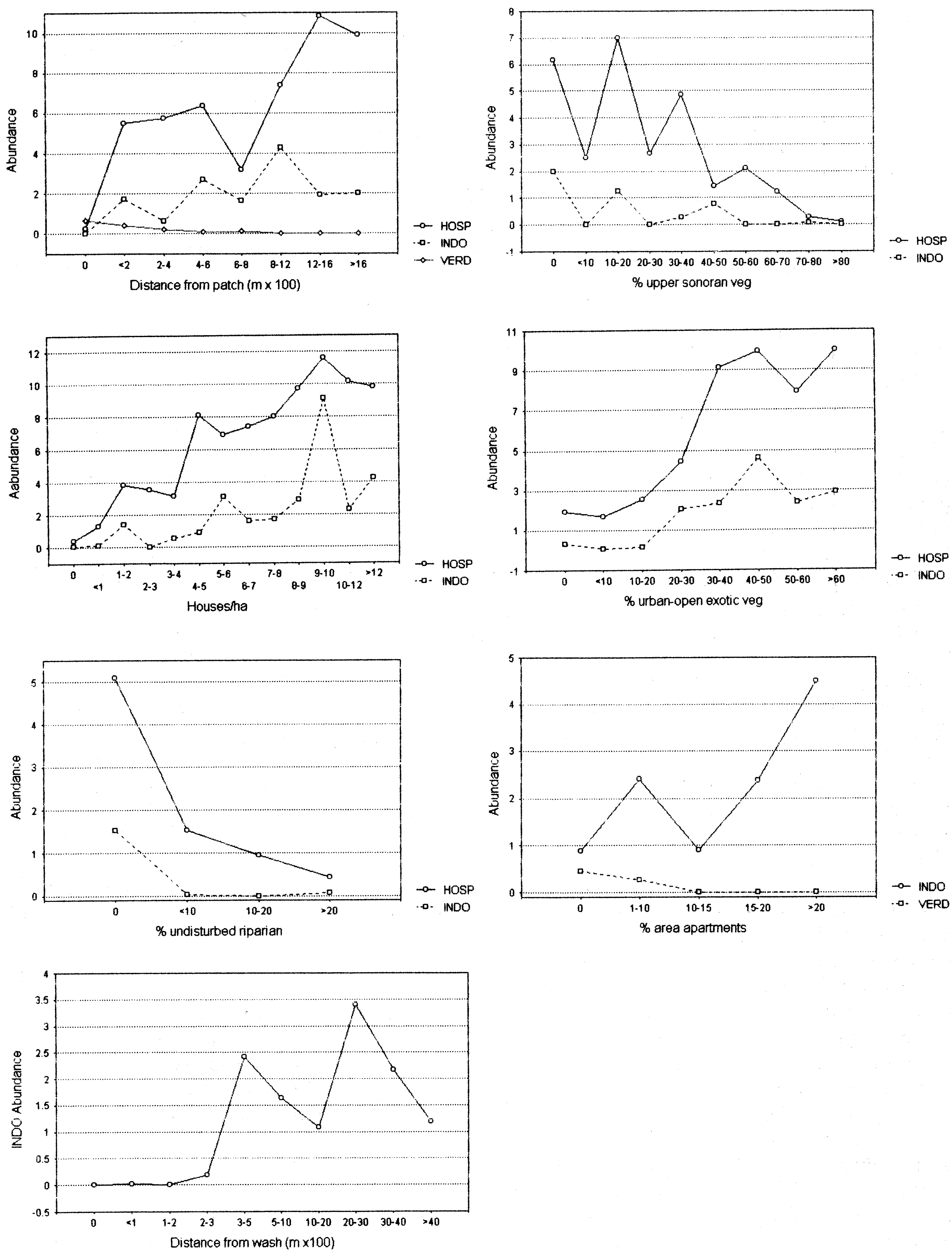


Figure 4. Wintering bird abundance trends over classes of habitat variables in Tucson in 1994. HOSP = house sparrow; INDO = Inca dove; VERD = verdin.

Lizards. Lower Sonoran vegetation correlated negatively with tree lizards, and positively with whiptail lizards (Fig. 5, Table 5). Upper Sonoran vegetation, percent undisturbed riparian, and distance from patch each correlated with 1 of the 4 lizard species. Distance from patch correlated positively with tree lizards, and upper Sonoran vegetation correlated negatively with them. Percent undisturbed riparian correlated positively with zebra-tailed lizards. House density did not correlate with any lizard species.

Nocturnal Rodents. All 4 house mice were captured in alleys in the high housing density sites, none were captured in any of the other density levels (Fig. 6). None of the 4 native species of rodents were captured in high housing density sites.

A total of 19 Bailey's pocket mice (Chaetodipus baileyi) were captured. Bailey's pocket mice were absent from both high density housing and the high density control. Therefore, I did not test them in a contingency table. They were evenly distributed between the low density control (n = 9) and the low housing density sites (n = 10).

White-throated wood rats were not encountered in the high housing density sites, but 36 individuals occurred in the other 3 areas. The distribution of individuals between high housing density and the other areas differed (2 tailed P = 0.006). A follow up test revealed no difference in frequency of occurrence between the remaining 3 areas (X^2 = 12.67, P = 0.779).

Merriam's kangaroo rats were also absent from high density housing. Forty individuals were captured in the other 3 areas. Merriam's kangaroo rats differed in abundance between all areas (two-tailed P, = 0.030). Merriam's kangaroo rats were also less abundant in the high density control than in either the low density housing or its control (X^2 = 21.40, P = 0.048). There was no difference in number of Merriam's kangaroo rats captured between the low density treatment and control (n = 13 in both cases).

The desert pocket mouse was represented by 45 individuals, none of which occurred in high housing density. The distribution of desert pocket mice differed (2 tailed P <0.001), but there was no difference in frequency of occurrence between the 3 remaining sites (X^2 = 0.53, P = 0.766).

Nocturnal rodent species richness did not differ between any of the 4 sites (2 tailed P = 0.576). However, total abundance was lower in both the high housing density (X^2 = 45.83, P <0.001) and the high density control (X^2 = 6.10, P = 0.047) than in either of the low density sites.

Wildlife Community Descriptors.

Non-native bird species richness and total abundance were positively correlated to house density, percent paved or graded, and percent urban-open exotic, and negatively correlated with upper Sonoran vegetation (Table 6; see Table 1 for full variable names). Evenness correlated positively with house density. Non-native species richness, total abundance, and evenness were all positively correlated.

Native breeding bird species richness correlated positively with upper Sonoran vegetation and negatively with distance from riparian. Total abundance of native birds correlated positively with plot heterogeneity. Evenness did not correlate with any variables. Native breeding bird species richness was not correlated with abundance or evenness, but abundance was negatively correlated with evenness.

Species richness and abundance for the breeding bird indicator guild correlated negatively with house density and percent urban-open exotic, and positively with upper Sonoran vegetation. Evenness correlated negatively with house density. Species richness, abundance, and evenness were all positively correlated.

The correlations between the 3 breeding bird groups and habitat variables disappeared during winter time. Bird species richness, abundance, and evenness for both wintering non-native and native bird groups were not correlated with any habitat descriptor. For non-native birds, the community descriptors were all positively correlated. For native birds, species richness and abundance were positively correlated, but not evenness.

Lizard richness, abundance, and evenness were not correlated with any habitat descriptors. All 3 lizard community descriptors were correlated.

Predictive Models

Breeding Birds. House density correlated with species richness for all 3 groups of birds (Table 6). The correlations with house density were negative for both native birds (r = -0.47) and the native indicator guild (r = -0.69), and positive for the non-native group (r = 0.80). Species richness in

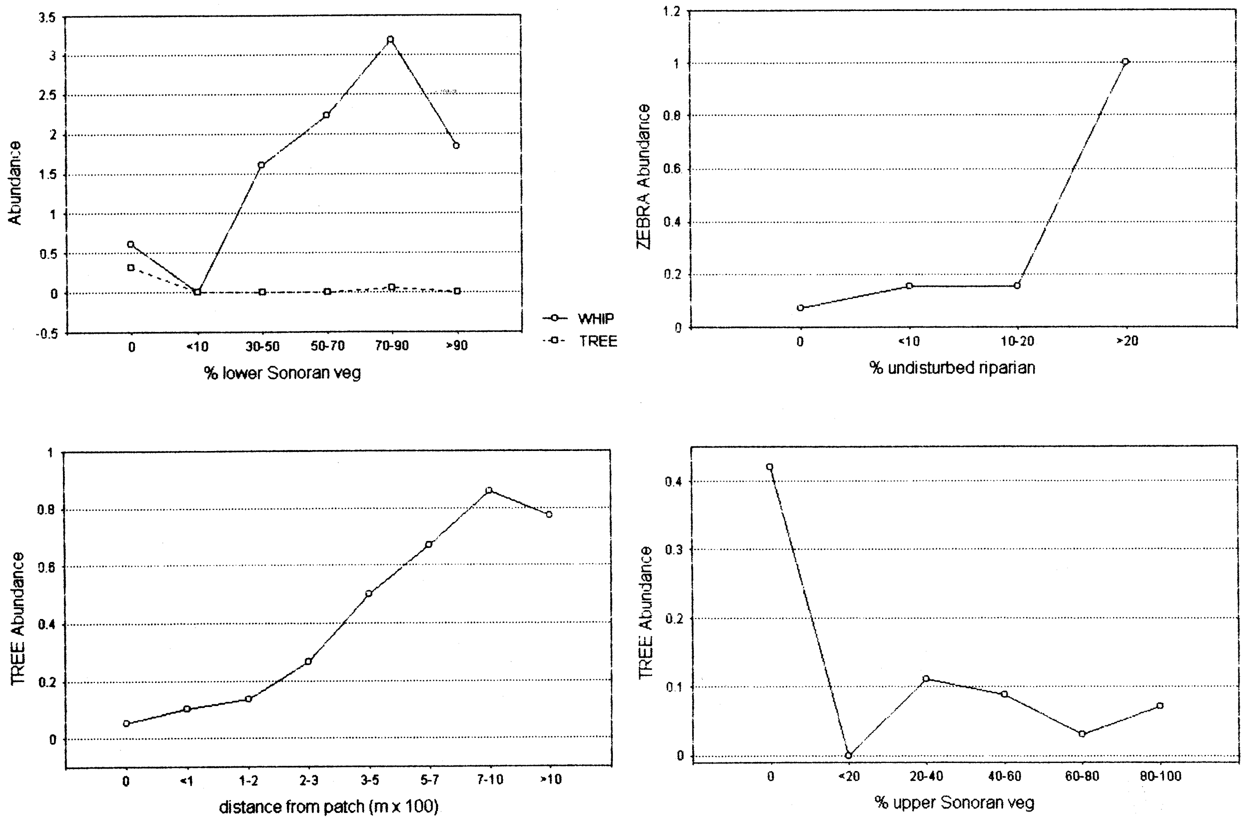


Figure 5. Lizard abundance trends over classes of habitat variables in Tucson in 1994. WHIP = whiptail lizard; TREE = tree lizard; ZEBRA = zebra-tailed lizard.

Table 5. Gamma correlations between 4 lizards and 5 habitat variables in Tucson. See Appendix C for full species names.

	HDEN	LSV	USV	RIPU	DISP
DSPN	-0.08	-0.15	0.10	0.34*	0.09
TREE	0.48*	-0.83*	-0.57*	-0.37*	0.56*
WHIP	-0.47*	0.68*	-0.01	0.25*	-0.36*
ZEBR	-0.46*	0.22	0.14	0.51*	-0.42*

* = significant at $P \leq 0.05$.

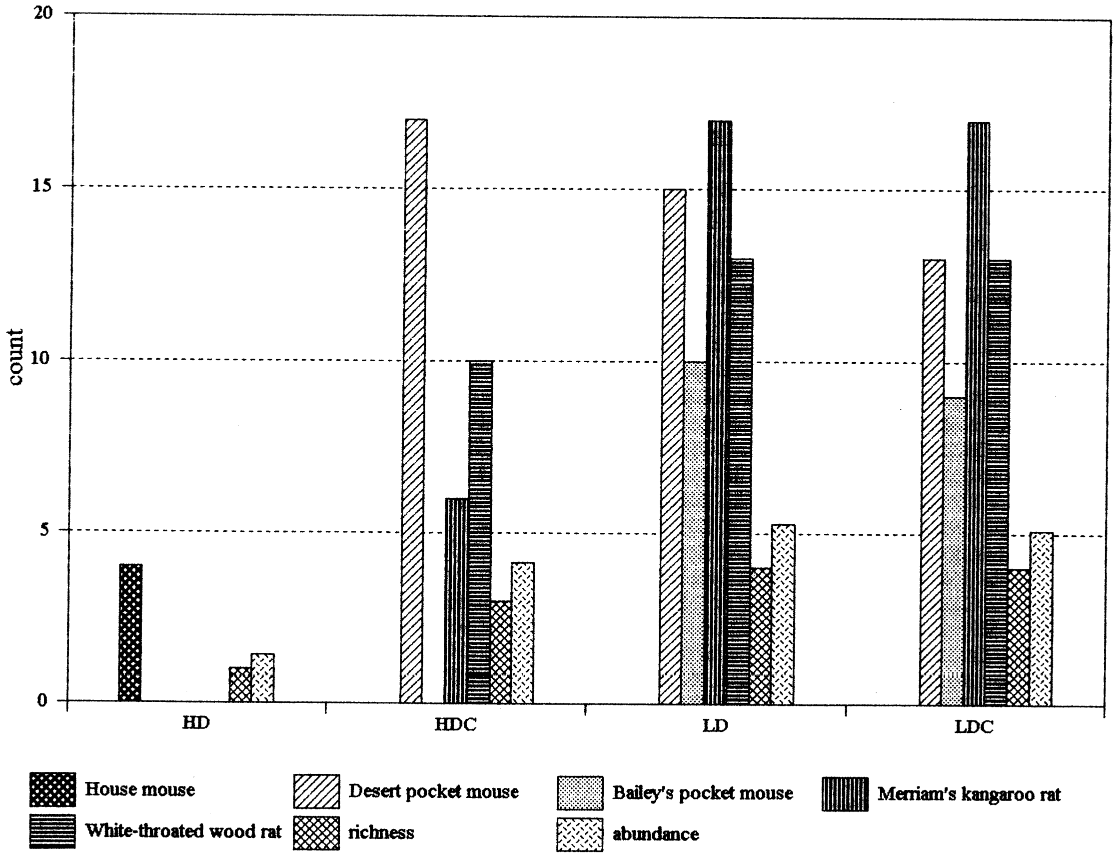


Figure 6. Nocturnal rodent abundances in 4 housing densities in Tucson in 1994: high density, high density control, low density, and low density control. (Total abundance square root transformed for graphing purposes only).

the non-native bird group was positively correlated with percent area of: apartments and small businesses; paved or graded land; urban-open non-native vegetation cover; and distance from: mainlands; >1 ha+ patches; and undisturbed washes. Non-native bird species richness was negatively correlated with percent area upper Sonoran vegetation, and undisturbed washes.

The best predictive equation for non-native bird species richness (NNATR) included house density (HDEN), percent area: paved or graded (PCTP), non-native urban-open vegetation (UROE), and upper Sonoran vegetation (USV):

$$NNATR = 0.545 + 0.196(HDEN) + 0.026(PCTP) + 0.009(UROE) - 0.002(USV).$$

This model (F = 125.93; df = 6, 314; P <0.001), had a multiple correlation coefficient of 0.84, and explained 71% of the variation in NNATR. The MSPR (0.745) was smaller than the MSE (0.763), indicating that the error mean square for this model gives an unbiased and appropriate indication of its predictive ability. In addition, there was no difference in slopes between models generated with predictive and testing data sets (P = 0.450).

Native breeding bird species richness (BREEDR) was positively correlated with percent area upper Sonoran vegetation and area of undisturbed washes, and negatively correlated with house density and percent area of: paved or graded land; urban open non-native vegetation cover; and all 3 distance measures. The best predictive equation included house density (HDEN), percent upper Sonoran vegetation (USV), and distance from undisturbed washes (DISR):

$$BREEDR = 10.803 - 0.466(HDEN) + 0.023(USV) - 0.001(DISR).$$

This model (F = 133.79; df = 3, 317; P <0.001) had a multiple correlation coefficient of 0.75, and explained 56% of the variation in BREEDR. The MSPR (3.571) was larger than the MSE (2.153). Therefore, the MSPR value should be referred to

Table 6. Community variable and habitat correlations for bird and lizard assemblages in Tucson. See Table 1 for full variable names.

Birds

	Breeding non-natives			Breeding natives		
	RICH	ABUN	EVEN	RICH	ABUN	EVEN
HDEN	0.80*	0.85*	0.59*	-0.47*	0.20*	-0.49*
PCTP	0.56*	0.59*	0.49*	-	-	-
UROE	0.63*	0.68*	0.42*	-	-	-
LSV	-	-	-	-	-	-
USV	-0.55*	-0.61*	-0.38*	0.56*	0.10	0.29*
HET	0.10	0.07	0.13	0.40	0.50*	-0.19
DISR	-	-	-	-0.56*	-0.13*	-0.25*
RICH	-	0.91*	0.74*	-	0.41*	0.09
ABUN	-	-	0.64*	-	-	-0.59*
EVEN	-	-	-	-	-	-

	Breeding indicator guild			Winter non-natives			Winter natives		
	RICH	ABUN	EVEN	RICH	ABUN	EVEN	RICH	ABUN	EVEN
HDEN	-0.69*	-0.69*	-0.58*	0.02	0.00	-0.01	0.07	0.09	0.07
PCTP	-0.49*	-0.42*	0.02	0.01	0.02	-0.03	-	-	-
UROE	-0.58*	-0.61*	-0.44*	0.10	0.10	0.05	-	-	-
LSV	-	-	-	-	-	-	-	-	-
USV	0.52*	-0.53*	0.44	0.01	-0.01	-0.02	0.02	0.01	-0.03
HET	0.11	0.14	-0.05	-0.17	-0.16	-0.16	-0.12*	-0.09	0.01
DISR	-	-	-	-	-	-	0.08	0.11	0.05
RICH	-	0.83*	0.85*	-	0.93*	0.82*	-	0.73*	0.37*
ABUN	-	-	0.63*	-	-	0.70*	-	-	0.00
EVEN	-	-	-	-	-	-	-	-	-

Lizards

	RICH	ABUN	EVEN
HDEN	-0.28*	-0.31*	-0.20*
UROM	0.22*	0.17*	0.19*
LSV	0.15	0.36*	0.06
HET	0.12	0.03	0.11
RIPU	0.26*	0.22*	0.25*
RICH	-	0.77*	0.85*
ABUN	-	-	0.54*
EVEN	-	-	-

* = significant at $P \leq 0.05$; (-) did not load into regression equations.

instead of the MSE when assessing the potential error in the predictive ability of this model in the future. This difference was only slight, however, and there was no difference between the slopes of the predictive and predicted models (P = 0.902).

Species richness for the native breeding bird indicator guild (INDG) was positively correlated with percent area upper Sonoran vegetation and undisturbed washes, and negatively correlated with house density and percent area of: paved or graded land; urban, open, non-native vegetation cover; and the 3 distance measures. The best predictive equation for indicator guild included house density, percent area paved or graded, percent area urban, open, non-native vegetation cover, and percent area upper Sonoran vegetation:

$$INDG = 1.584 - 0.200(HDEN) - 0.010(PCTP) - 0.008(UROE) + 0.003(USV).$$

This model (F = 119.93; df = 4, 316; P <0.000), had a multiple correlation coefficient of 0.78, and explained 60% of the variation in indicator guild. Cross validation revealed that the MSPR (0.246) was smaller than the MSE (0.495), indicating that this model gives an unbiased estimation of it's predictive ability. Again, there was no difference between the slopes of the predictor and the test data sets (P = 0.148).

Lizards. Lizard community total abundance (N) was negatively correlated with house density, and urban-open exotic vegetation (Table 6). Total abundance was positively correlated with percent area lower Sonoran vegetation and undisturbed wash cover. The best predictive regression equation incorporated lower Sonoran vegetation and undisturbed riparian:

$$N = 1.175 + 0.022(LSV) + 0.047(RIPU).$$

This model (F = 22.01; df = 3, 119; P <0.001), had a multiple correlation coefficient of 0.60, and explained 36% of the total variation in lizard community abundance.

Lizard species richness (R) was weakly correlated with 4 habitat variables (Table 6). Species richness correlated negatively with house density, and urban-open exotic vegetation. Species richness correlated positively with percent area mixed urban open cover, and undisturbed riparian. The best predictive equation for lizard species richness included house density, urban-open mixed vegetation, and undisturbed riparian:

$$R = 1.359 - 0.219(HDEN) + 0.211(UROM) + 0.185(RIPU).$$

This model (F = 7.65; df = 4, 118; P <0.001), had a multiple correlation coefficient of 0.54, and explained 21% of the variation in lizard species richness.

DISCUSSION

Study Design

My comparisons of land cover types were biased estimators of the actual percent occurrence for some of the habitat descriptors, because all of my census plots were located along roads and trails. This did not affect my analyses, because the variables representing natural areas were still well represented across the range of proportions of occurrence. In addition, this bias was justified by the large increase in sample size I gained by sampling along easily accessible routes.

In the instances in which I allowed inter-correlated habitat variables into correlation analyses, I did so because I felt that 1 or both variables were uniquely associated with wildlife variables. In addition, many of these habitat variables can be altered as urban expansion occurs. Therefore, it is important to know the effect that each has on wildlife. High housing density areas need not be dominated by exotic vegetation, nor do they need to be distant from natural habitat patches. Riparian and other native vegetation corridors could better connect habitat patches. Manipulation of distinct habitat variables will effect real changes in the wildlife assemblages in future developments.

Land Cover Associations

Much of the land surrounding Tucson is still in an undisturbed, natural state (Stenberg 1988), although rapid growth has continued in the area (Hazard and Burchell 1991). Most of the native ground cover that was thinned or otherwise degraded occurred either within the >1 ha native remnant habitat patches, or near mainland/residential development interfaces. Visible enhancement of native vegetation density was rare, typically occurring in older low density developments, and resulting from inadvertent runoff from roads and yards (W. Shaw, Univ. of Ariz., pers. commun.). Visibly thinned and over-abundant natural vegetation did not occur in enough plots to statistically relate to changes in wildlife distributions. However, based on the influence native vegetation volume has on native bird species abundance and diversity (Mills et al. 1989), degraded native habitat probably supports less native wildlife than undisturbed native areas.

Yards and other open-canopied areas were the most common cover types in residentially developed areas. Most of these areas were dominated by non-native vegetation, which occurred most often in the form of shade trees and ornamental plantings. The positive correlation between urban open non-native areas and house density indicates that high density residential areas are currently dominated by non-native vegetation. Both native and mixed-vegetation urban open areas were rare throughout my plots, and I could identify no trends in their distributions. Urban areas having >30% tree canopy closure were also rare throughout the study area, and will likely become more so as Tucson continues to grow and water demands increase.

The study area averaged 3.3 houses/ha (1.3 houses/ac), slightly higher than Stenberg's (1988) estimate of 2.5 houses/ha (1 house/ac). This discrepancy could be due to the fact that she measured land cover variables in a larger diameter area around each census point than I did, thus including a larger proportion of the existing undeveloped land in low density residential areas. It also may reflect actual changes that have occurred in the 7 years since her study. In my study, houses in high density developments covered approximately 22% of the surface area, and paved or graded surfaces covered an additional 25%. Thus, even in high density developments 50% of the ground cover may remain available for growing vegetative cover. The importance of addressing physiognomic and floristic characteristics in these areas becomes apparent when wildlife-habitat associations are examined. Results of these examinations are addressed in the following sections.

The negative correlation between percent area of undisturbed washes and distance from mainlands and patches indicates that undisturbed washes tended to occur more often in non or partially developed areas than in highly developed areas, where their value as dispersal corridors would likely be highest.

Wildlife - Land Cover Relationships

The correlations between individual species abundances and habitat variables indicate that bird and lizard (to a lesser degree) populations in urban environments respond to complex combinations of environmental factors much the same as they do in natural environments. Bird and lizard species formed several distinct groups based on their habitat relationships. Habitat-based groupings of wildlife have occurred in other urban studies as well (Beissinger and Osborne 1982; Lancaster and Rees 1979; Thomas et al. 1977). Many species associated with variables describing >1 habitat parameter, i.e., structural physiognomy (urban treed, savannah, and open areas), floristics (percent native, mixed, and non-native vegetation), thresholds of required habitat area, and distances from native, undeveloped habitats.

Non-native birds became dominant in the avian community as residential urbanization increased. Their association with non-native vegetation, and their negative associations with native vegetation cover suggests that the resource requirements of non-native birds are best met in urban environments (Emlen 1974).

Some native species mimicked non-natives in their response to increasing urbanization. Tree lizards, northern mockingbirds, and great-tailed grackles all increased in abundance with increased residential urbanization. In a review of existing information, I found no common differences in migration habit, preferred food type, feeding or nesting substrate use, or mean nest height between these species and those that were unaffected by urbanization.

A rather large group of native birds, including cactus wrens, Gila woodpeckers (*Melanerpes uropygialis*), curve-billed thrashers (*Toxostoma curvirostre*), mourning doves, house finches, brown-headed cowbirds (*Molothrus ater*), Anna's hummingbirds (*Calypte anna*), and northern cardinals (*Cardinalis cardinalis*) seemed relatively unaffected by urbanization. These birds did not correlate strongly with any habitat variables, and displayed stable abundances across the urban gradient.

Finally, several of the native species present in the study were sensitive to increasing urbanization. Whiptail and zebra-tailed lizards, verdins, pyrrhuloxias, black-tailed gnatcatchers, black-throated sparrows, and northern flickers were all negatively correlated with at least 1 of the descriptors of developed habitats. Two of these 5 bird species correlated with physiognomic descriptors, and all 5 correlated with at least 1 of the floristic descriptors. Most of those native species that were sensitive to residential urbanization depend on dense ground cover for feeding, nesting, or escape cover and share the trait of insectivory.

Breeding/Wintering Bird Habitat Use

The 8 bird species included in both the breeding and winter correlation analyses all demonstrated changes in habitat associations between the 2 seasons. For several of these species, the differences appear to be based on breeding habitat requirements. For instance, both mourning and Inca doves had stronger associations with urban savannahs during the breeding season than in winter, and both species are known to prefer to nest in open woodland areas (Ehrlich et al. 1988). Curve-billed thrashers correlated stronger with native habitat patches and native urban-open areas during the breeding season than in winter, when they seemed to increase use of both less natural vegetation structure and plant species composition. Verdins increased their associations with urban savannahs and native urban-open areas in the breeding season, and were found in less natural areas in winter. I did not identify whether the birds found in semi- or non-native areas in winter were juveniles or adults. Therefore, I do not know to what extent juveniles were contributing to the seemingly relaxed habitat requirements of many bird species in winter.

Wildlife Community Regulation

In urban areas it is important to understand whether changes in species richness are accompanied by disruptions in other factors that regulate wildlife communities (Hohtola 1978). The total abundance of individuals and evenness among species are also important regulatory mechanisms.

These 3 community parameters were regulated similarly for non-native birds, the indicator guild, and for lizards. The correlations between the 3 parameters indicates that as the number of species increased the number of individuals increased, and they were well distributed among the species. Correlations between the community descriptors of each wildlife group and habitat descriptors reveal those that are influential in maintaining community stability in residential urban areas. For lizards and the indicator guild, as residential urbanization increased, species richness decreased and there was a corresponding disruption in the mechanisms which regulate both the number of individuals and their distributions among species.

The community descriptors were not jointly regulated in the breeding native bird group. Species richness was the only community descriptor to correlate with manipulable habitat variables, and it did not correlate with either abundance or evenness. Evenness did not correlate with any habitat descriptors. This suggests that for this assemblage, evenness remains stable across the residential density gradient. The negative correlation between evenness and abundance indicates that as membership in this group increases, individuals are distributed unevenly among the species, resulting in a few dominant species and many poorly represented species.

Predictive Models

It is likely that there is an ecological relationship between housing density and other factors which jointly influence wildlife. High density housing was usually dominated by urban-open exotic vegetation, and both variables were negatively correlated with percent area of upper Sonoran cover and the 3 distance variables. These variables repeatedly entered the predictive models, indicating their importance to bird and lizard assemblage species richness.

My indicator guild was comprised of birds that would be expected to be sensitive to increasing residential density, since they use low growing native vegetation to nest and forage. The correlations between indicator guild species richness and habitat descriptors which describe reductions in low growing native vegetation support this. Tweit and Tweit (1986) reported that black-throated sparrows, black-tailed gnatcatchers (both members of indicator guild), and canyon towhees (*Pipilo fuscus*) were the most sensitive native species to reductions in native ground cover. I did not quantify the density of low growing native plants in developments. However, I observed a great reduction in them as development increased.

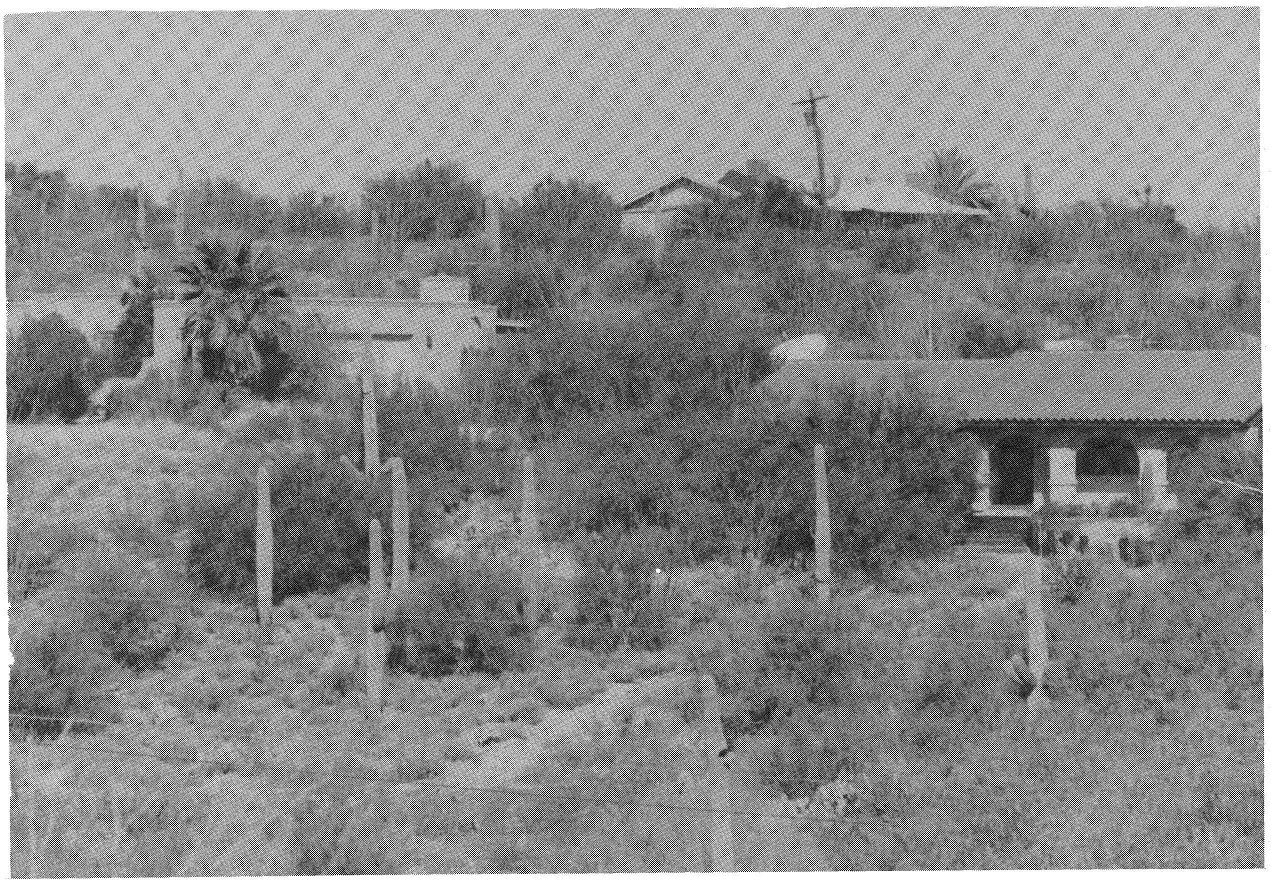
The inverse loadings of the same variables into the regression equations for indicator guild and non-natives indicates that certain native birds and the non-native species are highly polarized in their habitat requirements. Managing for sensitive native bird species may simultaneously decrease the dominance of non-natives in residential areas. Negative correlations by indicator guild with several urban variables indicate a strong aversion to residential developments. However, my results suggest that retaining patches of native Sonoran vegetation will result in the increased presence of indicator guild members within developed areas. In fact, many of the species that were sensitive to increased housing density were positively correlated with percent area of natural areas, and proximity to undeveloped habitat patches. Therefore, reducing housing densities and retaining areas of upper Sonoran vegetation and undisturbed riparian cover will retain higher numbers of many native breeding bird species. However, lowering housing densities will result in more rapid development of existing habitat, and will likely still result in sharp reductions in abundances of some of the most sensitive native bird species. Based on these habitat associations, clustering houses compactly and leaving intervening areas of native vegetation in a natural state may be another realistic development option. This possibility certainly needs further examination.

The correlations between the lizard community descriptors and the habitat variables were low. Refinements in lizard survey techniques are needed in urban areas, where traditional methods such as pitfall traps and drift fences encounter drawbacks not found in natural environments. Biased samples are likely in non-disruptive, time-and-area constrained surveys conducted in heterogeneous habitats due to differing densities of escape/hiding cover between habitat types. Refinements need to be made in this area of urban research.

The percent area of undisturbed washes loaded into both the lizard species richness and total abundance regression equations, indicating its importance in maintaining the natural structure of lizard communities. Undisturbed washes may be important dispersal routes for lizards, who are probably more limited by cover types such as road-ways than are birds (Gibbs et al. 1971). Retaining lower Sonoran vegetation cover, using at least 30-60% native plantings in residential areas, and building at lower housing densities will also positively affect the lizard community.

Nocturnal Rodents

It is not clear whether housing density is solely responsible for the difference in abundances that I found among rodent populations. I was able to control for distance from natural habitat patches by selecting residential developments that were adjacent to native habitat fragments. However, I could not control for vegetation differences between the low and high housing densities, and they did vary. The low density areas were dominated by upper Sonoran vegetation between most houses, while the high density areas contained reduced ground cover and large amounts of non-native vegetation between houses. In addition, although I did not quantify this, there seemed to be more cats and dogs in the high housing density areas. An increase in feral predator abundances in the high housing density areas could result in increased predation on rodents in and around these areas, and may help explain the absence of Bailey's pocket mice and the decreased abundance of Merriam's kangaroo rats from the high density control sites.



Moderately developed upper Sonoran desert habitat.

Residential development replacing native Sonoran vegetat:

CONCLUSIONS

Factors measurable on human-made, physiognomic, floristic, and spatial scales all influence wildlife populations. Residential urbanization corresponds with habitat changes on each of these scales. While some native species seemed unaffected by residential urbanization, several were moderately affected, and some were sensitive to even the smallest degree of disturbance by residential development. Several species responded to changes in housing density, and also to structural changes in the habitat that were not described by human-made structures. Furthermore, while some native species are tolerant of exotic vegetation, others are not. These exotic-intolerant species have native habitat patch size requirements that must be met if we are to ensure their continued presence within developing areas. Dispersal among patches must also be accounted for, and to that end patches must be arranged with inter patch distances that accommodate dispersal. Finally, since the birds in this study have demonstrated differences in seasonal habitat preferences, the best management plans will take into account habitat requirements during both breeding and winter seasons.

Developers, land use planners, and landscape architects must work with wildlife managers to maintain the greatest possible native species diversity and evenness. They then must plan developments with the habitat requirements of populations of these species in mind. While the continued presence of native species of wildlife in urban areas is important aesthetically, examinations of the reproductive success of urban wildlife populations are critical from an ecological stand-point. At present, we know little about whether urban populations of native wildlife are replacing themselves, or are maintained solely by immigration from outlying areas. If they are replacing themselves, what are the critical resources associated with the reproductive effort of each species? If immigration is responsible, from where are they migrating, and through what habitat types? In urban areas, patches and washes are commonly regarded as valuable to native wildlife as population refugia and travel routes (Goszczynski 1979a, Harris and Scheck 1991), but often without supporting biological data (Simberloff et al. 1992). Based on my estimates of abundances for many wildlife species in habitat patches and washes, it is questionable whether successfully reproducing populations exist in these areas in Tucson (see also Soule et al. 1988, Bolger et al. 1991). Without the answer to this question we do not know if it is ecologically better to leave native habitat patches and build outward, or to develop existing vacant lots and spare the urban edges of mainlands. If habitat patches do have value as population refugia and dispersal corridors, what spatial arrangements optimize their utility to wildlife? It also must be noted that native habitat patches have values beyond those considered here, such as for educational purposes and to raise wildlife awareness of urban dwelling humans (L. Adams, National Institute for Urban Wildlife, pers. commun.).

Finally, I was unable to identify common ecological traits among those native species that responded positively to residential urbanization versus those that were unaffected. This suggests that these species may be partitioning resources on a finer scale than I measured, or that they have behavioral or genetic predispositions towards these environments.

We must address these and other issues soon. Until we learn the answers to these questions we can not adequately manage for the continued presence of native wildlife within our expanding urban areas.

MANAGEMENT OPTIONS

Urban planners, developers, and landscape architects concerned with creating residential developments that will support complete assemblages of native species must consider factors on a broader scale than those that occur within the development boundary. In this study I have included factors that represent several scales of measurement, each of which directly affect wildlife populations and assemblages. The analyses and figures included in this report will allow managers and planners the ability to determine *a priori* the array of species likely to be affected by residential developments in Sonoran desert habitats. In addition, decisions can now be made in the planning stages of new developments which will help minimize the degree of disturbance to wildlife. The following developmental guidelines are offered to maximize abundances of native wildlife in residential areas.

1. Plots of wildlife abundances reveal that 2 native bird species present in the greater Tucson area decline sharply even in low density housing developments. Black-throated sparrows and black-tailed gnatcatchers may only be maintained within naturally vegetated, undeveloped areas. Leaving well distributed >1 ha blocks of native habitat will directly benefit these species in developed areas.

2a. Housing developments that are capable of supporting the full complement of native species are those which do not exceed 1-2 houses/ha. Furthermore, less than 20% of all yards should be dominated by exotic vegetation. Beyond these levels black-tailed gnatcatchers and black-throated sparrows are effectively eliminated, a sharp decline in verdin abundance occurs, and the non-native house sparrow clearly becomes dominant. Four native nocturnal rodent species present at 0.5 houses/ha drop out of the assemblage prior to 7.5 houses/ha residential densities. Lowering both housing density and the amount of exotic vegetation present will benefit both native bird and rodent assemblages, and lessen the degree of dominance of non-native birds.

2b. High density cluster housing has potential merit, but riparian corridors and >1 ha patches of vegetation must be maintained in a natural state with ≤500 m inter-patch distances. Sensitive species may persist in these patches, and other native species may become increasingly abundant. Cluster housing affects a smaller total land area than do other types of development, but alters the habitat within the developed area more than in low density developments.

3. Artificially increasing the tree canopy beyond 30% closure benefits only 1 native bird species, and therefore is not here considered a beneficial management practice for the wildlife included in this report.

4. Upper and lower Sonoran and undisturbed wash vegetation should be retained whenever possible, ideally at minimum of 20-30% each of Sonoran and wash cover per total development area. Increased abundances of Zebra-tailed lizards, whiptail lizards, and pyrrhuloxias result, along with reductions in non-native birds. Increasing the use of upper Sonoran vegetation will also benefit other members of the breeding native bird community.

5. Native habitat patches ≥1 ha in size should be maintained in a network with a mean interpatch distance ≤0.4 km. Beyond 200-400 m from native patches several native bird species are effectively eliminated, and house sparrows become dominant. Tree lizards are virtually absent from areas <0.5 km from patches, but are abundant in urban areas beyond this distance. (Incentives could be offered to increase developers' willingness to leave greater proportions of their land undeveloped and in a natural state.)

6. High priority should be placed on preserving riparian and wash vegetation. Proximity to wash vegetation correlated with increased species richness for breeding native birds. Wash vegetation cover also positively influences lizard species richness and abundance.

These recommendations are for optimizing the abundances of species that are sensitive to residential urbanization, and those that were correlated with habitat variables. Several native bird and lizard species exist in Tucson whose abundances were stable across the urban gradient, and their presence did not correlate with any of the habitat variables that I measured. These species will still be represented in developments that do not meet the guidelines suggested here. Their continued presence in residential areas may depend upon factors which I have not identified.

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Appendix A. Breeding bird common and scientific names, codes, distribution among plots, and abundance.

Bird Species	Code	# Plots	Abundance
house sparrow (*Passer domesticus*)	HOSP	248	2,031
mourning dove (*Zenaida macroura*)	MODO	315	996
house finch (*Carpodacus mexicanus*)	HOFI	315	848
Inca dove (*Columbina inca*)	INDO	163	368
Gambel's quail (*Callipepla gambelii*)	GAQU	208	317
white-winged dove (*Zenaida asiatica*)	WWDO	240	249
verdin (*Psaltriparus minimus*)	VERD	242	214
cactus wren (*Campylorhynchus brunneicapillus*)	CAWR	259	204
Gila woodpecker (*Melanerpes uropygialis*)	GIWO	237	188
rock dove (*Columba livia*)	RODO	63	161
curve-billed thrasher (*Toxostoma curvirostre*)	CBTH	250	143
European starling (*Sturnus vulgaris*)	EUST	134	111
northern mockingbird (*Mimus polyglottos*)	NOMO	144	88
pyrrhuloxia (*Cardinalis sinuatus*)	PYRR	132	59
black-throated sparrow (*Amphispiza bilineata*)	BTSP	92	58
great-tailed grackle (*Quiscalus mexicanus*)	GTGR	75	58
black-tailed gnatcatcher (*Polioptila melanura*)	BTGN	111	54
northern cardinal (*Cardinalis cardinalis*)	NOCA	79	32
brown-headed cowbird (*Molothrus ater*)	BHCO	68	32
phainopepla (*Phainopepla nitens*)	PHAI	54	25
Anna's hummingbird (*Calypte anna*)	ANHU	63	25
northern flicker (*Colaptes auratus*)	NOFL	69	22
ash-throated flycatcher (*Myiarchis cinerascens*)	ATFL	56	19
brown-crested flycatcher (*Myiarchis tyrannulus*)	BCFL	48	15
black-chinned hummingbird (*Archilochus alexandri*)	BCHU	38	12
purple martin (*Progne subis*)	PUMA	13	10
western kingbird (*Tyrannus verticalis*)	WEKI	24	9
canyon towhee (*Pipilo fuscus*)	CYTO	26	9
Lucy's warbler (*Vermivora luciae*)	LUWA	17	7

Appendix A. (continued) Breeding bird common and scientific names, codes, distribution among plots, and abundance.

Bird Species	Code	# Plots	Abundance
rufous-winged sparrow (*Aimophila carpalis*)	RWSP	22	7
greater roadrunner (*Geococcyx californianus*)	GRRO	15	5
Bell's vireo (*Vireo bellii*)	BEVI	10	5
Say's phoebe (*Sayornis saya*)	SAPH	10	3
hooded oriole (*Icterus cucullatus*)	HOOR	10	3
ladder-backed woodpecker (*Picoides scalaris*)	LBWO	9	3
bronzed cowbird (*Molothrus aeneus*)	BRCO	5	2
rufous-crowned sparrow (*Aimophila ruficeps*)	RCSP	6	3
northern oriole (*Icterus galbula*)	NOOR	6	2
common raven (*Corvus corax*)	CORA	5	2
lesser goldfinch (*Carduelis psaltria*)	LEGO	5	2
killdeer (*Charadrius vociferus*)	KILL	4	2
American kestrel (*Falco sparverius*)	AMKE	4	1
Scott's oriole (*Icterus parisorum*)	SCOR	4	1
Cooper's hawk (*Accipiter cooperii*)	COHA	4	1
turkey vulture (*Cathartes aura*)	TUVU	1	1
bushtit (*Psaltriparus minimus*)	BUSH	3	1
lark sparrow (*Chondestes grammacus*)	LASP	3	1
red-tailed hawk (*Buteo jamaicensis*)	RTHA	3	1
loggerhead shrike (*Lanius ludovicianus*)	LOSH	2	1
yellow warbler (*Dendroica petechia*)	YEWA	2	1
rock wren (*Salpinctes obsoletus*)	ROWR	2	1
Harris' hawk (*Parabuteo unicinctus*)	HAHA	2	1
barn swallow (*Hirundo rustica*)	BASW	2	1
song sparrow (*Melospiza melodia*)	SOSP	1	1
Cassin's kingbird (*Tyrranus vociferans*)	CAKI	1	1
cliff swallow (*Hirundo pyrrhonota*)	CLSW	1	1
lesser nighthawk (*Chordeiles acutipennis*)	LENI	1	1
violet-green swallow (*Tachycineta thalassina*)	VGSW	1	1

Appendix B. Wintering bird common and scientific names, codes, distribution among plots, and abundance.

Bird Species	Code	# Plots	Abundance
house sparrow (*Passer domesticus*)	HOSP	164	1,227
mourning dove (*Zenaida macroura*)	MODO	183	1,217
house finch (*Carpodacus mexicanus*)	HOFI	123	385
Inca dove (*Columbina inca*)	INDO	64	344
Gambel's quail (*Callipepla gambelii*)	GAQU	43	89
rock dove (*Columba livia*)	RODO	23	142
cactus wren (*Campylorhynchus brunneicapillus*)	CAWR	91	129
Gila woodpecker (*Melanerpes uropygialis*)	GIWO	92	128
verdin (*Psaltriparus minimus*)	VERD	97	124
European starling (*Sturnus vulgaris*)	EUST	49	122
curve-billed thrasher (*Toxostoma curvirostre*)	CBTH	74	96
phainopepla (*Phainopepla nitens*)	PHAI	43	75
white-crowned sparrow (*Zonotrichia leucophrys*)	WCSP	22	74
great-tailed grackle (*Quiscalus mexicanus*)	GTGR	21	67
northern mockingbird (*Mimus polyglottos*)	NOMO	57	63
black-throated sparrow (*Amphispiza bilineata*)	BTSP	32	48
black-tailed gnatcatcher (*Polioptila melanura*)	BTGN	38	46
Anna's hummingbird (*Calypte anna*)	ANHU	28	34
pyrrhuloxia (*Cardinalis sinuatus*)	PYRR	19	23
lark bunting (*Calamospiza melanocorys*)	LABU	4	22
northern cardinal (*Cardianlis cardinalis*)	NOCA	12	15
northern flicker (*Colaptes auratus*)	NOFL	13	14
yellow-rumped warbler (*Dendroica coronata*)	YRWA	12	14
ruby-crowned kinglet (*Regulus calendula*)	RCKI	10	12
rufous-winged sparrow (*Aimophila carpalis*)	RWSP	6	8
canyon towhee (*Pipilo fuscus*)	CYTO	6	7
white-winged dove (*Zenaida asiatica*)	WWDO	5	7
brown-headed cowbird (*Molothrus ater*)	BHCO	1	7
ash-throated flycatcher (*Myiarchis cinerascens*)	ATFL	5	5
greater roadrunner (*Geococcyx californianus*)	GRRO	4	4

Appendix B. (continued) Wintering bird common and scientific names, codes, distribution among plots, and abundance.

Bird Species	Code	# Plots	Abundance
rock wren (*Salpinctes obsoletus*)	ROWR	4	4
common raven (*Corvus corax*)	CORA	2	4
brewer's blackbird (*Euphagus cyanocephalus*)	BRBL	1	4
Say's phoebe (*Sayornis saya*)	SAPH	2	3
black-chinned sparrow (*Spizella atrogularis*)	BCSP	1	3
red-tailed hawk (*Buteo jamaicensis*)	RTHA	2	2
black-chinned hummingbird (*Archilochus alexandri*)	BCHU	2	2
rufous-crowned sparrow (*Aimophila ruficeps*)	RCSP	1	2
American kestrel (*Falco sparverius*)	AMKE	1	1
sharp-shinned hawk (*Accipiter striatus*)	SSHA	1	1
northern harrier (*Circus cyaneus*)	NOHA	1	1
black-throated gray warbler (*Dendroica nigrescens*)	BTGW	1	1

Appendix C. Lizard common and scientific names, codes, distribution among plots, and abundance.

Lizard species	Code	# Plots	Abundance
whiptail lizard (*Cnemidophorus* spp.)	WHIP	67	122
tree lizard (*Urosaurus ornatus*)	TREE	36	33
desert spiny lizard (*Sceloporus magister*)	DESP	40	27
zebra-tailed lizard (*Callisaurus draconoides*)	ZEBR	23	19
lesser earless lizard (*Holbrookia maculata*)	LEEA	7	4
Clark's spiny lizard (*Sceloporus clarkii*)	CLSP	3	5
greater earless lizard (*Cophosaurus texanus*)	GREA	3	4
side-blotched lizard (*Uta stansburiana*)	SBLI	2	1
regal horned lizard (*Phrynosoma solare*)	RHLI	1	1

Appendix D. Nocturnal rodent common and scientific names, codes, distribution among plots, and abundance.

Rodent Species	Code	# Plots	Abundance
desert pocket mouse (*Chaetodipus penicilatus*)	DEPO	6	45
Merriam's kangaroo rat (*Dipodomys merriami*)	MEKA	6	40
white-throated wood rat (*Neotoma albigula*)	WTWO	6	36
Bailey's pocket mouse (*Chaetodipus baileyi*)	BAPO	4	19
house mouse (*Mus musculus*)	HOMO	2	4

Appendix E. Habitat descriptors, units of measurement[a], and definitions.

General Habitat: classification of each point into 1 of 3 nominal categories based on the existence and type of remnant native ground cover. If present, vegetation was classified as either lower or upper Sonoran desert. A plot was classified as completely developed if no vestiges of original vegetation could be found.

House density: number of houses tallied within 100 m radius of plot center, converted to # houses/acre, of # houses/10 acres (for scaling in graphical presentations). All houses ≥50% included in habitat plot were included.

Percent area house: % ground covered by houses and associated outbuildings (sheds, barns, etc.).

Percent area apartments & small businesses: % ground covered by apartment buildings and small businesses. Small businesses are here defined as non-residential buildings allowed within areas zoned primarily as residential or non industrial (e.g. Circle K, schools, churches).

Percent area paved or graded: all land either paved or graded such that no vegetative growth exists. This includes roads, sidewalks, graded vacant land, and sides and bottoms of cemented washes.

Percent continuous exotic tree cover: summed areas of all canopies of exotic shade trees such as *Eucalyptus* spp., alleppo pines, and tamarisk.

The classification criterion for urban areas was: yards and other areas that have been altered from a natural state by either grading during development, the presence of grass or stone ground coverings, or the presence of exotic plants around dwellings. Native vegetation in these areas was either planted after development or specifically left during development on a plant by plant basis.

Percent urban treed: yards that have been altered from a natural structural and floristic state (see above) and containing >60% tree canopy cover. Only areas that were not built on, paved, or graded were included in tallies of % canopy cover. Three classes of urban treed were constructed:

- native: >60% native trees
- mixed: 30-60% native trees
- exotic: >60% exotic trees.

Percent urban savannah: yards that have been altered from a natural structural and floristic state (see above) and containing 30-60% tree canopy cover.

- native: >60% native trees, including tree cacti
- mixed: 30-60% native trees, including tree cacti
- exotic: >60% exotic trees, including tree cacti

Percent urban open: yards that have been altered from a natural structural and floristic state (see above) and containing <30% tree canopy cover.

- native: >60% native trees, including all cacti
- mixed: 30-60% native trees, including all cacti
- exotic: >60% exotic trees, including all cacti

Percent open water: pools, etc.

Appendix E. (continued) Habitat descriptors, units of measurement[a], and definitions.

Native areas were all areas dominated by native vegetative cover in a natural floristic and physiognomic state, and not graded, paved, or cemented.

<u>Percent native vegetation:</u> % native areas occurring in the following classifications.

<u>Percent lower Sonoran dominant cover:</u> Predominantly *Larrea tridentata*, *Ambrosia* spp., *Prosopis* spp., and their associates.

% visibly sparse: visibly thinned by trampling, driving, or physical removal of plants resulting in lowered plant densities, and increased amounts of bare or open areas .

% natural density: not visibly altered from natural plant densities.

% visibly overabundant: plant densities enhanced by planting and/or watering in excess of naturally occurring precipitation.

<u>Percent upper Sonoran dominant cover:</u> Vegetation dominated by *Cercidium* spp., *Carnegiea gigantea*, *Olneya tesota* and their associates.

% visibly sparse: visibly thinned by trampling, driving, or physical removal of plants resulting in lowered plant densities, and increased amounts of bare or open areas .

% natural density: not visibly altered from natural plant densities.

% visibly overabundant: plant densities enhanced by planting and/or watering in excess of naturally occurring precipitation.

<u>Percent Mesquite bosque:</u> mesquite thickets associated with washes and riparian zones.

<u>Percent riparian wash:</u> washes categorized by level of disturbance.

<u>% disturbed wash:</u> >2 m wide at channelized sandy bottom, (easily definable on a 1:4800 scale aerial photograph), with at least some riparian vegetation along 1 bank. Otherwise classified as "paved" category.

<u>% undisturbed wash:</u> >2 m wide at channelized sandy bottom, includes bottoms and associated riparian vegetation (other than mesquite bosque) in natural undisturbed state.

<u>Presence of loose cats in plot:</u> yes or no.

<u>Presence of loose dogs in plot:</u> yes or no.

<u>Plot heterogeneity:</u> # of different primary cover classes/plot.

<u>Distance (m) to mainland:</u> mainland is the matrix of native habitat, not fragmented from the continuum of desert vegetation surrounding greater Tucson or isolated by residential or other developments. The edge of mainland is defined by a straight line drawn between the outer edge of disturbance associated with the 2 houses adjacent to the line end, and beyond which no more houses exist. This measurement is the linear distance from each census point to the nearest mainland area.

<u>Distance (m) to patch >1 ha in size and containing native vegetation:</u> Linear distance from each census point to the nearest undeveloped patch containing native vegetation and >1 ha in size. This is the smallest

Appendix E. (continued) Habitat descriptors, units of measurement[a], and definitions.

patch size found to contain all of the native bird species locally present in a similar study conducted in San Diego (Soule et al. 1988, Bolger et al. 1991). In addition, no patch was allowed to be more than 2 times wider than long.

Distance (m) to nearest riparian zone: linear distance from each census point to the nearest riparian zone in an undisturbed natural state, and which is connected to a native habitat block >10 ha in size. For this measurement roadways do not count as interruptions to connectivity.

[a] All % ground cover measurements derived from counts of all dots overlapping each distinct cover type, [illegible] acetate dot matrix overlay.

Germaine, S.S. 1995. **Relationships of birds, lizards, and nocturnal rodents to their habitat in the greater Tucson area, Arizona.** Arizona Game and Fish Dep. Tech. Rep. 20. 47p.

Abstract: I examined population and community descriptors of 3 wildlife assemblages across the residential gradient from undisturbed-natural to highly developed land in Tucson, Arizona, from March 1994 through February 1995. Breeding birds were sampled in 334 random plots, and wintering birds and lizards were sampled in subsets of 305 and 130 plots, respectively. In addition, I sampled nocturnal rodents at 8 sites representing 3 housing densities. Land cover type, habitat structure, plant species composition, and distances from population refugia were measured in all plots. I identified habitat associations for breeding bird, wintering bird, and lizard species. Housing density best explained the variation in species richness for non-native, native, and an indicator guild of breeding birds, and for lizards. The percent of paved areas, exotic, upper Sonoran, and undisturbed riparian vegetation in plots, and distance from undisturbed washes also predicted bird and lizard species richness. Lizard abundance was best explained by the amount of lower Sonoran vegetation and undisturbed riparian vegetation within plots. House mice (*Mus musculus*) were the only nocturnal rodents encountered in high density (7.5 houses/ha) housing areas. Two of the native rodent species were less abundant in the high density control than in low density (0.5 houses/ha) areas. While rodent species richness did not differ significantly among levels of housing density, total abundance was lower in the high density housing and control. Development strategies for optimizing urban wildlife habitat in Tucson in the future are discussed.

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Layout, design, and typesetting by Vicki L. Webb
Photos by:
Jeff Howland (Pages 30, 36)
Bob Miles (Pages iv, 6, 34, 35)
Ray Schweinsburg (Cover, Pages vi, 12)

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